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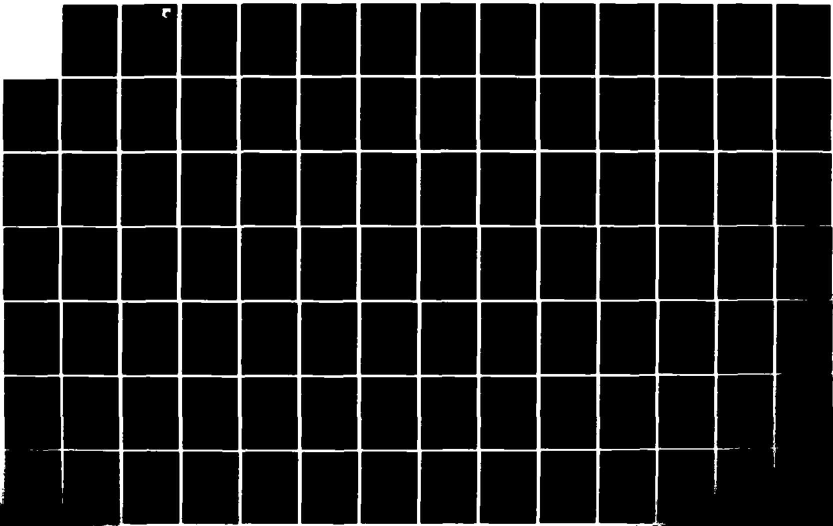

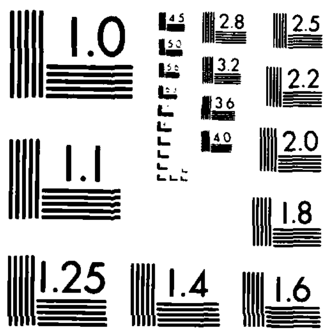

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INTEGRATED CONTROL SYSTEM ENGINEERING SUPPORT

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DECEMBER 1984

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEM COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

This technical report has been reviewed and is approved for publication.

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This report covers development, test, integration and documentation of software and specialized interfaces for use in the Flight Control Development Laboratory (AFWAL/FIGX); analysis of redundancy management for a multi-channel Flight Control System in the Digital Synthesis Flight Engineering Facility; support for the advanced development programs through analysis of multi-channel Flight Control Systems and the independent assessment of prime contractors efforts in the areas of control law development and coding; and software development for these and other programs on PD-11, AN/AYK-15, ROLM, and FAI machines and other equipment.

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LIST OF ACRONYMS

A	Airframe
A/D	Analog to Digital
AA	Air Axis
ADPO	Advanced Development Program Office
AFB	Air Force Base
AFCS	Automatic Flight Control System
AFFTC	Air Force Flight Test Center
AFLOAD	Aeromodel Software
AFTI	Advanced Fighter Technology Integration
AFWAL	Air Force Wright Aeronautical Laboratory
AMAS	Automatic Maneuvering Attack System
AMRAAM	Advanced Medium Range Air to Air Missile
ASTEC	Advanced Speech Technology Experimental Configuration
BA	Body Axis
BCIU	Bus Control Interface Unit
BMU	Bus Monitor Unit
C	Computers/COMMON Storage Location
CCB	Configuration Control Board
CCC	Cruise Camber Control
CDC	Control Data Corporation
CDR	Critical Design Review
CM	Configuration Management
CMO	Configuration Management Office
CPL	Computer Program Library
CPLC	Computer Program Library Catalog
CR	Change Requests
CRT	Cathode Ray Tube
D	Dynamics
DATA1	Data Recording Software
DATA2	Data Reduction Software
DFCS	Digital Flight Control System
DFGS	Digital Flight Guidance System
DFRF	Dryden Flight Research Facility
DIGISYN	Digital Synthesis Simulator
DISPIC	Discovision Display Software
DMA	Defense Mapping Agency
DMA	Direct Memory Access
DOF	Degree of Freedom
DR	Discrepancy Report
DSF	Digital Synthesis Facility
DSFEF	Digital Synthesis Flight Engineering Facility
DTP	Document Tracking Program
EFGS	Earth Frame Guidance System
ENG	Engine Display Software
EOM	Equations of Motion
FAA	Federal Aviation Administration
FBW	Fly by Wire
FCDL	Flight Control Development Laboratory
FCL	Flight Control law

FCLSW	Flight Control Law Software
FCRC	Flight Control Research Center
FCS	Flight Control System
FDL	Flight Dynamics Laboratory
FEF	Flight Engineering Facility
FFC	Flight Fire Control
FLCC	Flight Control Computer
FLIR	Forward Looking Infrared Receiver
FLOLS	Fresnel Lens Optical Landing System
FLTDIR	Flight Director Software
FRA	Frequency Response Analysis
FRR	Flight Readiness Reviews
FSCU	Flight Control Skew Control Unit
FY	Fiscal Year
G	Geophysical
GDFW	General Dynamics/Fort Worth
GE	General Electric
GFE	Government Furnished Equipment
GPCD	General Purpose Control and Display
HQDT	Handling Qualities During Tracking
HSD	Horizontal Situation Display
HUD	Head Up Display
I/O	Input/Output
IBU	Independent Backup Unit
IC	Initial Condition
ICD	Interface Control Document
ICSES	Integrated Control Systems Engineering Support
IFFC	Integrated Flight Fire Control
IOC	Input/Output Controller
ISA	Integrated Servo Actuator
JTF	Joint Test Force
KEYTES	Multifunction Control Display Software
L/D	Lift over Drag
LAMARS	Large Amplitude Multimode Aerospace Research Simulator
LCOS	Laser Control Optical Sensor
LED	Light Emitting Diode
LSO	Landing Signal Officer
MAGIC	Microcomputer Applications of Graphics and Interactive Communications
MAW	Mission Adaptive Wing
MCC	Maneuver Camber Control
MCR	Mechanization Change Requests
MDS	Mass Data Storage
ME/GA	Maneuver Enhancement/Gust Alleviation
MFCS	Manual Flight Control System
MFK	Multifunction Keyboard
MFS	Master Function Select
MIL-STD	Military Standard
MLC	Maneuver Load Control
MLS	Microwave Landing System
MMM	Multi-Mode Matrix
MMP	Master Mode Panel
MPD	Multi Purpose Display

LIST OF ACRONYMS, Cont.

MSIP	Multinational Staged Improvement Program
MSNSET	Mission Setup
NASA	National Aeronautics and Space Administration
NAV	Navigation
OFP	Operational Flight Program
PA	Power Approach
PCM	Pulse Code Mudulation
PDR	Preliminary Design Review
PEPSI	Pictorial Emergency Procedure Speech Integration
PIO	Pilot Induced Oscillation
PMC	Performance Monitor and Control
RAD	Radian
RADC	Rome Air Development Center
REL WIND	Relative Wind
RFP	Request for Proposal
RID	Review Item Disposition
RM	Redundancy Management
RMVS	Rigid Model Visual System
RT	Remote Terminal
S	Sensor
S/W	Software
S/WRR	Sofware Requirements Review
SAIF	Standardized Avionics Integrated Fuzing
SAR	Simulation Acceptance Review
SCB	Software Control Board
SCN	Specification Change Notice
SCT	Systems Control Technology
SEC	Second
SPAM	Speech Application to Multifunction Control
SPR	Sofware Problem Report
SPS	Samples per Second
SSIU	Simulation Subsystem Integration Unit
SVC	Smooth Variable Camber
SWIM	System Wide Integrity Management
SYSCOM	System Common
TACT	Transonic Aircraft Technology
THRCMD	Throttle Command
TM	Telemetry
TMS	Terrain Map Simulation
TOC	Test Operators Console
TPR	Test Procedures Review
TRACS	Transport Advanced Control Synthesis
T&E	Test and Evaluation
URT	Universal Receiver Transmitter
URT	Universal Remote Terminal
USAF	U.S. Air Force
USN	U.S. Navy
VC	Variable Camber
VSD	Vertical Situation Display
VTAS	Vertical True Air Speed
V&V	Verification and Validation

LIST OF SYMBOLS

a_{ij}	Elements of direction cosine matrix from earth-fixed tangent plane axis to body axis
$A_{XBA}, A_{YBA}, A_{ZBA}$	Total thrust acceleration due to engine
$\overline{C}$	Reference length
C_A, C_Y, C_N C_ℓ, C_m, C_n	Aerodynamic coefficients, body axes
e	Base of the natural logrithm
F_X, F_Y, F_Z	Components of aerodynamic force along wind (AA) or body (BA) axes
g	Acceleration due to gravity
h	Altitude
$\dot{h}$	Altitude rate
I_{XX}, I_{YY}, I_{ZZ}	Principal moments of inertia, or X,Y,Z axis moments of inertia
I_{XZ}	XZ product of inertia (stability axes)
L, M, N	Components of aerodynamic moment along body axes
L_T, M_T, N_T	Components of thrust moment along wind (AA) or body (BA) axes
M	Mach number
M_3	Multivariable Multi-Mode
n_z	Normal acceleration
P	Roll rate
ρ	Density of the air
P, Q, R	Components of missile angular rate about body axes
Q	Pitch rate
q_d	Dynamic pressure
R_s	Slant range from missile to origin of tangent plane

LIST OF SYMBOLS, Cont.

S	Reference area
TAS	True airspeed
T_X, T_Y, T_Z	Components of thrust force along wind (AA) or body (BA) axes
V	Magnitude of velocity
V_{AT}	Velocity with respect to air
V_X, V_Y, V_Z	Components of velocity, tangent plane axes
W_{TX}, W_{TY}, W_{TZ}	Components of wind, including gusts
X,Y,Z	Components of position, tangent plane axes
α	Angle of attack (AOA) (alpha)
β	Angle of sideslip (beta)
Δ	Delta - incremental change
δ	Surface displacement (delta)
δ_C, δ_A	Control surface deflections causing moments about vehicle axes (e.g., aileron, canards)
δ_{CC}, δ_{AC}	Control surface deflection commands from navigation and stabilization autopilot loop
δ_f	Flaperon displacement
δ_{i_H}	Stabilizer incidence angle displacement
δ_R	Rudder displacement
γ	Flight path angle (gamma)
$\int$	Integration symbol
θ	Pitch altitude (theta)
τ	Time constant
ψ	Heading or yaw angle (psi)

I. INTRODUCTION

The Integrated Control System Engineering Support Contract covered the period of 17 September 1979 through 2 April 1984. The objective of this effort was to provide engineering analysis and software support to the Flight Control Division of the Air Force Flight Dynamics Laboratory on several programs concerned with the formulation, development, and evaluation of advanced concepts in flight control technology.

1.1 SCOPE OF WORK PLANNED

This effort was intended to make available engineering analysis and software development support to programs across the Flight Control Division. Among the tasks to be performed were: The development, test, integration, and documentation of software and specialized interfaces for use in the Flight Control Development Laboratory, including support of the Digital Synthesis Flight Engineering Facility; support of advanced development programs through analysis in the area of redundancy management for multi-channel flight control systems and independent assessment of the findings of the prime contractors in the area of control law development and coding; and software development for these and other tasks on PDP-11, AN/AYK-15, ROLM, EAI, and other equipment.

1.2 PERSONNEL REQUIREMENTS

The minimum qualifications of the personnel required for the program are listed below. Actual versus planned labor hours for each of the labor categories are given in Table 1.2-1.

Table 1.2-1 Labor Hours - Actual vs. Planned

Labor Category	Planned Hours by Fiscal Year					Planned Total		Actual Total		
	79/80	81	82	83	84	Hours	Percent of Total	Hours	Percent of Total Actual	Percent of Total Planned
Program Manager	2430	2080	1640	1040	260	7450	3.5	6875	4.9	3.2
System Integration Engineer	5550	5200	3290	3120	780	17940	8.4	9070	6.5	4.3
Senior System Software Engineer	9010	10400	4860	2080	520	26870	12.6	36610	26.2	17.2
System Software Engineer	18380	20800	9530	2080	520	51310	24.1	27943	20.0	13.1
Senior Flight Control Engineer	4510	4160	2600	2080	520	13870	6.5	27181	19.5	12.8
Flight Control Engineer	11090	10400	4860	2080	520	28950	13.6	1928	1.4	0.9
Avionic Systems Engineer	6930	8320	4770	3120	780	23920	11.3	4820	3.5	2.3
Circuit Design Engineer	5550	6240	2250	--	--	14040	6.6	--	0.0	0.0
Documentation Specialist	2430	2080	1640	1040	260	7450	3.5	3448	2.5	1.6
Draftsman	2430	4160	1730	--	--	8320	3.9	--	0.0	0.0
Technical Typist	4680	4160	2510	1040	260	12650	6.0	21723	15.5	10.2
TOTAL PLANNED	72990	78000	39680	17680	4420	212770	100.0			
TOTAL ACTUAL	36378	36510	34928	27256	4526			139598	100.0	65.6

Program Manager

The contractor shall designate a Program Manager who will be responsible for the overall administration of the technical effort. He shall devote sufficient attention to the program to assure proper reporting, coordination, and administration of the contractual effort. He shall be the point of contact with the government for technical matters.

Systems Integration Engineer. Duties are to perform integration of processors, multiplex equipment, control and displays, support hardware, and software and to determine hardware and software requirements for an aircraft flight simulation facility.

Education/Experience Requirements. A Systems Integration Engineer shall have an appropriate engineering degree and at least five years of experience in hardware and software integration. An appropriate masters degree may be substituted for two years of experience.

Senior Software Engineer. Duties are to design, develop, and maintain software used in real-time simulation, data acquisition and reduction, avionics, and flight control systems.

Education/Experience Requirements. A Senior Software Engineer will have an appropriate degree in engineering or computer science and a minimum of four years experience in software management, design, development and testing. An appropriate Masters Degree may be substituted for two years of experience. Experience shall include aircraft flight control systems, redundancy management, and simulation development.

System Software Engineer. Duties include design, development, and implementation of system software for simulation aerodynamics/flight control, redundancy management, data acquisition and reduction, and simulation control.

Education/Experience Requirements. A system Software Engineer shall have an appropriate degree in engineering or computer science and at least three years experience in software design, development, and testing. An appropriate Masters Degree may be substituted for one year of experience. Experience shall include real-time aircraft simulation and avionics/flight control system development and modeling.

Senior Flight Control Systems Engineer. Duties will include studies of advanced flight control system architectures and redundancy management techniques for digital fly-by-wire systems.

Education/Experience Requirements. A Flight Control Systems Engineer shall have an advanced degree in Electrical Engineering, Aeronautical Engineering, or Mathematics with at least five years of industrial experience in work with high reliability control systems and redundancy management.

Flight Control Systems Engineer. Duties are to perform analysis of flight control system implementations and to study and recommend systems to meet specifications.

Education/Experience Requirements. A Flight Control Systems Engineer shall have an appropriate degree in engineering and at least four years experience in design and analysis of aircraft flight control systems.

Avionic Systems Engineer. Duties will include integration of avionic and flight control systems to investigate methods of increasing system effectiveness, particularly in the area of integrated flight and fire control.

Education/Experience Requirements. An Avionic Systems Engineer shall have an appropriate engineering degree and at least four years experience in avionic systems development. Experience

shall include fire control algorithm development, display requirements, and system integration.

Circuit Design Engineer. Duties include design of analog and digital interface hardware for a real-time aircraft simulation facility.

Education/Experience Requirements. A Circuit Design Engineer shall have a degree in electrical engineering or acceptable alternate and three years experience in design, development, and testing of analog and digital hardware. Experience with DEC PDP-11, EAI 8400, and EAI PACER hardware is desirable.

Documentation Specialist. Duties will include establishment and maintenance of document control procedures for specifications, technical reports, manuals, and other reference materials for advanced development programs.

Education/Experience Requirements. Experience in document control for government R&D programs is required.

Draftsman. Duties are to prepare diagrams and engineering drawings for documentation of hardware and software designs. Work requires practical knowledge of MIL-Standards and drafting methods, procedures, and techniques.

Education/Experience. A Draftsman shall be a high school graduate with at least two years drafting experience.

Technical Typist. Duties include final typing of technical materials insuring proper layout and assembly of documents in a form suitable for publication.

Education/Experience Requirements. A Technical Typist shall be a high school graduate with at least two years experience typing

technical material.

1.3 PROGRAM AREAS

The contract work accomplished involved seven major program areas, plus Program Management, which are listed below with a brief description of each and a reference to the section of this report which describes the work. The labor hours applied to each program area are shown in Table 1.3-1 at the end of this section.

1.3.1 Digital Synthesis Flight Engineering Facility (Section 2.1)

The Digital Synthesis Facility (DIGISYN) was developed in early 1974 as an outgrowth of the DAIS program. This program exercised in-flight processors in a real-time simulation environment. The Flight Dynamics Laboratory decided to utilize this concept to test actual flight control system performance and pilot-in-the-loop response. DIGISYN was established to analyze the applications of avionics military standards to digital flight control technology. For the duration of the contract, tasks were performed following the facility plan. These tasks can be broken down into the areas of support software (drivers, interfaces, corrections), flight processor development (incorporation of new hardware), concept test support (simple versus full redundancy management), integration and validation support (flight control/equations of motion), experiment support (iteration rate study), and software documentation.

1.3.2 AFTI/F-16 Program (Section 2.2)

The AFTI/F-16 Advanced Development Program is a joint USAF, Navy, and NASA effort aimed at the development, integration, and flight test evaluation of emerging technologies for improving fighter aircraft mission effectiveness. Major development thrusts include Digital Flight Control System, Direct Force and Weapon Line Control, Pilot Vehicle Interface and Automatic Maneuvering Attack System (AMAS). Development of an advanced highly reliable digital flight control system (DFCS) is the core technology building block for accomplishing the overall AFTI/F-16 objectives.

Over the course of the program, SCT reviewed and evaluated all software documentation produced by the prime contractor. All documentation was evaluated with a view to discovering errors, inconsistencies, omissions, or other significant departures from accepted industry standards and known system operating characteristics. Detailed comments and suggestions were provided to the Program Office and all review activities were documented in the weekly activity reports as well as the monthly progress and status reports.

SCT also provided continuous design review support throughout the program. This support included participation in all system design reviews, safety reviews, and numerous technical coordination meetings, including the Flight Readiness Review, which were conducted at General Dynamics Ft. Worth as well as at the Program Office at WPAFB.

In addition to providing an independent assessment of the software design, SCT was also tasked to provide analysis in support of design trade-off studies, and to permit the program office to properly evaluate potential changes to the program. SCT also provided on-site support to the AFTI/F-16 Joint Test Force (JTF) at Edwards AFB. These services were provided starting with the digital flight control system (DFCS) devlopment phase at General Dynamics Fort Worth and continuing through actual flight test. SCT supported this program in 5 distinct areas:

- Development of six-degree-of-freedom batch simulation of the AFTI/F-16.

- Systems engineering support to the analysis, development effort, and flight test of the DFCS phase.
- Support of flying qualities test and evaluation of DFCS.
- Systems engineering support of development efforts required for the AMAS phase.
- Documentation control and clerical support to the JTF.

1.3.3 Transport Advanced Control Synthesis Program (Section 2.3)

The emphasis of the TRACS program is to demonstrate advanced control synthesis applications for transport aircraft and to evaluate the feasibility of crew station integration concepts. The TRACS program is comprised of four main activities, namely, (1) flight trajectory investigation, (2) throttle/energy management, (3) transport advanced control technology and (4) tanker integration and evaluation. The flight test bed to demonstrate the post-1980 military transport mission is the Speckled Trout (C135-C) aircraft which is equipped with a digital flight control system (Sperry), advanced displays, and a number of inertial/area navigation (Collins) systems. Flight control performance improvements have been demonstrated by incorporation of digital systems. Analysis and applications of integrated throttle/flight path control techniques enable a pilot or automatic control system to regulate an aircraft's potential and kinetic energy. The TRACS program has utilized a systematic design approach to systems integration investigations of controls/displays/sensors/pilot to provide the potential for increasing operational mission performance.

SCT provided support in the following areas: Software Acceptance Review, Flight Control Law Analysis, Simulation/Validation Facility Development Support, and Flight Control Test Support.

1.3.4 Flight Control Development Laboratory Support (Section 2.4)

SCT provided support to the Control Synthesis Branch (AFWAL/FIGD) in the areas of establishing a software management methodology and

software tools to implement this methodology. FIGD is responsible for the Flight Control Development Laboratory (FCDL) which provides the simulation developmental tools to test advanced flight technology concepts.

The FCDL contains a number of simulation facilities including the LAMARS, Multicrew Simulator, Fighter/Bomber Simulator, Crew System Integration Facility, Flight Control Actuation and Hydraulics System Facility, and two in-flight simulators (T-33 In-Flight Simulator and the Total In-Flight Simulator). Since particular software management requirements vary from facility to facility, an in depth examination of the FCDL software development methods was performed by talking with numerous FCDL personnel. The information collected in these interviews was mapped into requirements to be addressed in the ensuing development of a software management methodology.

The software management methodology which was developed addressed all aspects of software development from initial software planning to software control and maintenance. This methodology was presented in four separate volumes of software standards consisting of Software Management Standards, Software Development and Test Standards, Software Documentation Standards, and Software Configuration Management Standards.

The second phase of the support to FIGD consisted of development of two software support packages, one to be used by FIGD in controlling developed software and the other to be used for tracking FCDL documents. These software programs were the Computer Program Library Catalog (CPLC) Software and the Documentation Tracking Program (DTP) software.

The CPLC software helps the configuration management office manager of FIGD maintain inventories of software documents and products, and status logs on change requests and specification change notices.

Because the FCDL facility is supported by a large number of manuals and drawings which from time to time are revised and have been distributed to various engineers, a need exists to be able to track the various documents. The DTP software provides a user friendly

software tool that will aid in tracking these facility documents (manuals, drawings, etc.).

1.3.5 Control Systems Analysis Tasks

1.3.5.1 Avionics/Flight Control Reconfiguration (Section 2.5.1)

This study examined strategies for increasing the reliability of integrated control of flight systems through reconfiguration, particularly the concept of virtual redundancy. Virtual redundancy, possible in highly integrated avionics/flight control system architectures, involves the reconfiguring of system resources so as to create redundancy on demand.

Integrated control of flight implies a high degree of dynamic coupling between avionics and flight control. Accordingly, much current emphasis is being placed on highly integrated, bus-oriented architectures and bus topologies which exhibit a high degree of connectivity between flight control and certain avionics function (e.g., Integrated Fire/Flight Control, Integrated Flight/Trajectory Control, Terrain Following/Terrain Avoidance, etc.).

The Reconfiguration Study, along with its successor experiments, attempted to exploit this high degree of architecture integration and bus connectivity to enhance "coverage" and to recover lost critical functions.

The Work accomplished in this task is summarized below:

1) Adapted to the Flight Engineering Facility a multiprocessor System Exec from the DAIS Exec and associated support software.
2) Integrated a multiprocessor avionics/flight control architecture with real-time simulation capability.
3) Devised a workable method for employing virtual redundancy and reconfiguration concepts for applications which are tolerant of reduced update rates or temporary suspension of output command (i.e., highly stable aircraft).

4) Established ability to load a processor over 1553 bus and restart.
5) Established ability to dynamically initialize a processor.
6) Collected preliminary data on time-to-load over bus and time-to-initialize/recover.
7) Developed all-S/W simulation tool for analyzing alternative algorithms and architectures.
8) Identified limitations of and problems with existing laboratory hardware and software (Exec) which were GFE for this study.

1.3.5.2 Multivariable Control of Wingshape (Section 2.5.2)

Demonstration of the mission-adaptive wing (MAW) technology, also called "smooth variable camber" (SVC), is an objective of the Air Force's performance, control, and mission effectiveness benefits for an aircraft with a smooth variable camber wing will be demonstrated by the AFTI F-111 airplane. The design objective is to use the variable wing camber to optimize the wing's aerodynamic efficiency over a broader speed range and to provide additional control devices. Under the current AFTI F-111 contract, two approaches to automatically control wing camber are being investigated: "preprogrammed" and "self optimizing". However, identified weaknesses of each of these control modes suggest that to enable SVC benefit realization, research and development in this area should continue.

Optimum camber selection is a multivariable control problem and may require use of modern control techniques for satisfactory performance. Prior to the initiation of the program described in this report, the available technical data base was inadequate to support a multivariable control design implementation within the AFTI F-111 MAW development program schedule. In response to this deficiency, the Flight Control Division of the Flight Dynamics Laboratory formulated an exploratory study to develop the modern control design technology for aircraft applications. Objectives of this technology development

are listed as follows:

- o Evaluate the application of modern control design techniques to the synthesis of complex aircraft control laws.
- o Define multifunctional/multivariable control law structures which are adapted to advanced aircraft mission requirements.
- o Assess the design impact of multivariable/multifunctional control systems.

A summary of the work accomplished in this task is given below:

1) Developed the design objectives and requirements for the flight control system of an aircraft that integrates smooth wing camber control with conventional aircraft controls.
2) Developed a conceptual design of a multivariable/multimode flight control system.
3) Developed an overview of multivariable design techniques and a detailed description of linear quadratic synthesis methods.
4) Prepared a technology assessment of the proposed flight control system and recommendations for a research and development program that addresses these issues.

1.3.5.3 FIREBOLT Target Drone Analysis, Simulation and Flight Test Support (Section 2.5.3)

This task was undertaken to develop a simulation which provides Eglin Air Force Base Armament Division an in-house, quick reaction capability to evaluate the FIREBOLT performance and stability independent of the prime FIREBOLT contractor's assessments and to provide a tool for the FIREBOLT flight test program.

The main objectives of this project were to:

1) Develop, update, maintain and validate the six-degrees-of-freedom (6DOF) digital simulation. This included all design changes to the FIREBOLT vehicle made by Teledyne Ryan or the Air Force and included model updates based on post-flight test analysis. All updates were documented and provided to the Air Force. Validation of the simulation was accomplished by matching simulation performance characteristics to flight test results. The 6 DOF simulation was written in FORTRAN IV and subsequently modified to FORTRAN V, and is compatible with the CDC 6600 at Eglin Air Force Base.
2) Provide an independent assessment of the FIREBOLT flight control system design, including design changes and modifications. Also provide written and oral comments on FIREBOLT contract data items in the areas of:
   - Flight control system
   - Aerodynamics
   - Test plans, reports, and analysis.
3) Provide pre- and post-flight test analyses on each flight test vehicle to include, but not be limited to, flight performance, profile, sensitivity analysis, diagnostic analysis of problems and recommendations.
4) Provide operational instructions to Air Force personnel in the use of the 6DOF simulation.

1.3.6 Control/Display Development (Section 2.6)

SCT has been supporting the Crew Systems Integration Branch of the Air Force Wright Aeronautics Laboratories (AFWAL/FIGR) in the development of control and display technology. The digital synthesis simulator (DIGISYN) was used to investigate the impact of digital avionics information on pilot/aircraft performance and effectiveness. The support tasks to FIGR have included:

- 2-D Display Software Support: Examine the feasibility of

integrating altitude, lateral performance, predicted lateral performance and situation information on a single display surface.

- Color Terrain Display System Support: Investigate the feasibility of using computer image generation techniques to display terrain and cultural features. Definitize requirements for achieving this capability on the DIGISYN and/or recommend equipment and software needed to achieve this display in a real-time simulation environment.
- Speech Applications (SPAM) Experiment Support: Investigate voice activation and control of aircraft displays.
- Flat Panel Display Support: Test the possibility of using flat-panel LED multimode matrix displays as a multi purpose display to present real-time flight parameter and system status information.
- Pictorial Emergency Procedures/Speech Interaction Support (PEPSI): Compare different methods of communicating emergency procedures to the pilot. The methods compared were: a pictorial display, an alphanumeric display, and an aural warning/procedure checklist.
- Microprocessor Application of Graphics and Interface Communication (MAGIC): Development of a "dynamic mockup", driven by microprocessors, which can be used for testing possible applications of color flight displays and voice technology for a future advanced tactical fighter.

Systems Control Technology, Inc. provided systems and software development expertise necessary to implement and conduct the above mentioned studies/support tasks. This support included:

- systems and software functional and interface requirements definition
- Development of software interface drivers
- Generation of tailored operating systems
- Design, development, test and documentation of

software modules to meet software requirements

- Modification of existing DIGISYN software to meet software requirements
- Integration and checkout of experiment software modules
- Experiment support to aid in conducting experiments, and gathering and reducing data.

During these support efforts, software design documents and code were prepared and delivered to AFWAL/FIGR to provide continuity and control of all support tools.

1.3.7 AFTI/F-111 Program

The Advanced Fighter Technology Integration (AFTI) F-111 Program consists of two phases. The first phase addresses the design and development of a variable camber (VC) mission adaptive wing (MAW) and includes a flight test program. Testing of the MAW will be performed using a manual pilot-controlled fly-by-wire system for setting MAW leading and trailing edge deflections. This manual system provides for evaluation of general quasi-static aerodynamic performance and for developing flight control parameters.

Phase two of the AFTI/F-111 Program addresses the design and development of a modification to incorporate an automatic flight control system (AFCS) capability for the MAW that is compatible with the manual control system. A second flight test program is planned to evaluate the MAW with automatic controls and demonstrate the performance benefits provided by the AFCS functions.

SCT has been providing systems and software support to AFWAL/FIMS for the AFTI/F-111 MAW program. This support has occurred in three areas: software management, simulation support, and control system design.

SCT has provided software support to address the management aspects of the AFTI/F-111 MAW Manual Flight Control System (MFCS) and Automatic Flight Control System (AFCS) software development. Support

Table 1.3-1 Labor Hours by Program Area

Program Area	Labor Hours by Fiscal Year					Total	
	79/80	81	82	83	84	Hours	Percent of Total
Digital Synthesis Flight Engineering Facility	12406	8613	7587	6766	1106	36478	26.1
AFTI/F-16	9222	11612	9242	9147	--	39223	28.1
TRACS	1005	587	--	--	--	1592	1.1
Flight Control Development Lab	2903	2347	1285	--	--	6535	4.7
Control Systems Analysis	4919	2668	1674	--	--	9261	6.6
Control/Display Development	1883	3554	6620	6598	1721	20376	14.6
AFTI/F-111	--	2214	2297	735	198	5444	4.0
Program Management and Final Report	4040	4915	6223	4010	1501	20689	14.8
TOTAL	36378	36510	34928	27256	4526	139598	100.0

has included: review of all developing contractor software documents and many system documents, providing document review comments to the Air Force, active participation in all system and software design reviews of the MAW program, and working closely with the Air Force and NASA in performing a critical review of the contractor software development plan to provide guidance in the areas of software documentation, software configuration control, and software development milestone reviews.

SCT has also provided simulation development support at NASA/Dryden. This support consisted of detailed review of system and software requirements for the MAW MFCS and AFCS, and assistance in implementation of these requirements into a functional simulation of the MAW system.

SCT also performed a study to evaluate an alternative approach to controlling wingshape design. The objectives of the study were to define potential multivariable control law structures which are suitable for active wingshape control, recommend design and algorithm implementation techniques, and assess the design impact of a multivariable active wingshape control system.

1.4 CONTRACT DELIVERABLES

Over the course of the contract, SCT delivered more than 15,000 pages of documentation, including 54 progress reports and more than 200 specifications, technical memoranda, technical reports, and the software documents listed in Table 1.4-1 at the end of this Section.

1.5 CONCLUSIONS AND RECOMMENDATIONS SUMMARY

Digital Synthesis Facility

The Digital Synthesis Flight Engineering Facility has provided a means to obtain hands-on experience in the application and use of control systems and applicable software standards. The experience gained in the use of the facility implies a strong need for facility capabil-

ities to emulate system designs. A second-generation Digital Synthesis Facility should have the capability to address critical flight control technology issues in the areas of system requirements specifications, flight control systems test and evaluation, DFCS design, redundancy management, control law design, and handling quality criteria.

AFTI/F-16 Program

Independent contractor support for a program of this type is extremely important in the areas of documentation review; software design review, analysis, and V&V audit; redundancy management; simulation and analysis; flight test planning; documentation control; and flight test data analysis. The need for independent analysis is even more acute during the AMAS phase of the program because of the additional complexity which arises from several new techniques which are to be integrated and evaluated simultaneously.

Transport Advanced Control Synthesis (TRACS)

The TRACS program has utilized a systematic design approach to system integration investigations of controls/displays/sensors/pilot to provide the potential for increasing operational mission performance.

Flight Control Development Laboratory

Adherence to desired standards for software development, management, and configuration control in a simulation facility with many diverse and complex requirements is a difficult goal. The software management methodology developed by SCT in concert with FIGD should enable attainment of that goal, but requires commitment by FIGD management and acceptance by the work force.

Avionics/Flight Control Reconfiguration

The reconfiguration study provided an initial step in the determination of the feasibility of the concept of virtual redundancy and reconfiguration as a means of increasing the reliability of integrated avionics/flight control systems, and identified future

study requirements.

Multivariable Control of Wingshape

Modern control design techniques are well-suited for the development of complex control systems such as the mission adaptive wing. There are a number of technology/design issues which still need to be addressed in order to quantify the benefits of an optimal performance seeking flight control system.

FIREBOLT Target Drone

The simulation, developed by SCT, provides a quick-reaction capability to evaluate the FIREBOLT's performance and stability.

Advanced Control/Display Concepts

The support contractor's role in the work being performed not only encompassed software development, but also involved the areas of systems analysis and systems engineering. In many cases, the level of support needed for a simulation development task included extensive knowledge of the hardware being used in the effort as well as an understanding of the experimental design and statistical techniques being used in the study.

AFTI/F-111 Program

With the current trends in computer hardware, software development costs are becoming the major portion in the acquisition cost of systems involving hardware and software. To reduce these costs software management must work toward the following objectives:

- Reduce resource expenditures in software development.
- Improve software development resource estimating.
- Avoid duplicate development efforts.
- Improve quality of software.
- Reduce software maintenance efforts.

In future development efforts, the Air Force should initially

make certain that the development contractor has a well-defined, phased software management approach with scheduled review milestones. As the software development progresses, the Air Force should actively participate in the software review process to assure that initial development plans are being met and that these plans are still aligned with final design goals.

Management Lessons Learned

1) Task instruction procedures were very efficient and provided adequate flexibility for quick response to changing requirements.
2) The nature of the work assigned required a higher percentage of senior technical personnel than originally planned.
3) Program management and clerical support required a higher percentage of the total effort than originally estimated due to the diversity of the technical tasks.
4) The assignment of individual project managers in each of the major program areas provided the necessary diverse technical management expertise, and enhanced the day-to-day technical interface with the corresponding Air Force Project Engineers.
5) The utilization of sub-contractors and consultants allowed quick reaction to unforseen special technical support requirements on an ad hoc basis, and minimized the effects of work load fluctuations.
6) Continuity in assigned tasks enhanced "corporate memory" and minimized start-up effort on new tasks.
7) Computer time and travel requirements in support of the Advanced Development Programs were four times that originally estimated.

Table 1.4-1(a) Documentation Summary - DSFEF

Document Title	Delivery Date	Comments
Terrain Board Product Specification	01 AUG 80	Added to Spec. SB600-509 EOM Models STI-80-OPR-068
Configuration Management Plan for AFWAL/FIGX Software Development	15 FEB 80	Developed by E. Lehman
AN/AYK-15 BCIU Driver Test Report	13 FEB 80	Tech Memo 104-80-1
AN/AYK-15 BCIU--Floating Point Conversions Report	03 MAR 80	Tech Memo 104-80-2
Selecting Three Values from a Quad-Redundant Signal Set	02 APR 80	Tech Memo 111-80-3
BCIU Computer Program Product Spec. (CPPS)	10 JUL 80	STI-80-SAD-081
Redundancy Management (RM) CPPS	25 AUG 80	STI-80-SAD-089
Technical Report for the Redundancy Management Software Test Results	25 AUG 80	STI-80-SAD-093
RSX-11M Multi-User System Generation	11 JUL 80	Tech Memo 108-80-13
DSFEF Software Configuration Management Plan	05 AUG 80	Tech Memo 107-80-14
Demonstration of the AFFDL A-7D Flight Control System	12 SEP 80	STI-80-OPR-016

Table 1.4-1(a) Documentation Summary - DSFEF (Cont.)

Document Title	Delivery Date	Comments
Test Plan for Module Checkout and Verification of the Single Channel Flight Control Software	25 AUG 80	STI-80-OPR-097
JOVIAL Flight Control Law Flowcharts and Variables	12 AUG 80	STI-80-OPR-076 TM 108-80-15
PMC Subsystem CPPS	24 SEP 80	STI-80-OPR-139
Technical Report for the FEF PMC Subsystem Development	29 SEP 80	STI-80-OPR-140
EOM Evaluation Report	10 DEC 80	Tech Memo
Demo Al Test Plan/Procedure	07 JAN 81	STI-81-OPR-002 TM-131-81-02
Demo Al Software Modification Documentation	13 JAN 81	STI-81-OPR-005 TM-131-81-03
Alternative Techniques for Accessing Data from the AN/AYK-15	05 JAN 81	Memo for the Record
Demo A2 Test Plan/Procedure	13 FEB 81	STI-81-ADM-171
Demo A2 Test Report	13 FEB 81	STI-81-ADM-172
Users Manual for the FCL and EOM Systems	13 FEB 81	STI-81-ADM-175
Primary Flight Control System Documentation	10 MAR 81	TM-131-81-08

Table 1.4-1(a) Documentation Summary - DSFEF (Cont.)

Document Title	Delivery Date	Comments
Demo A1 Test Report	12 MAR 81	STI-81-ADM-264
Synchronization Operating Procedure	10 MAR 81	Appendix to STI-81-ADM-175
Detailed Test Procedures for Austere Single Channel Flight Control System Iteration Rate Study	07 APR 81	Revised and Resubmitted 27 MAY 81
Iteration Rate Study Post-Test Requirements Technical Memo	30 APR 81	STI-81-ADM-560
EOM System Flowcharts	27 MAY 81	STI-81-ADM-263
URT Crossloading Procedure	15 JUN 81	
FCL Documentation (2 volumes)	30 JUN 81	STI-81-ADM-261
PMC Status Letter	01 JUL 81	STI-81-ADM-848
BCIU CPPS (update)	09 SEP 81	STI-81-ADM-995
EOM 4-Port Analysis	03 DEC 81	No number assigned
Flight Control Software Voter/Monitor Technical Memo	10 JUN 82	ST-82-ADM-144
Redundancy Management CPPS	30 JUN 82	ST-82-ADM-143 (Reflect Simplified Redundancy Management)

Table [illegible] Documentation Summary [illegible]

Document Title	Delivery Date	Comments
Equations of Motion Module Analysis	07 JUN 82	ST-82-ADM-135
Flight Control Software Channel Selection Technical Memo	26 JUL 82	ST-82-ADM-202
Flight Control Software Simplified Redundancy Management Technical Memo	03 SEP 82	ST-82-ADM-224
Redundancy Management CPPS (update)	03 SEP 82	STI-80-SAD-089
Flight Control Software (update)	30 SEP 82	ST-82-ADM-242
	29 OCT 82	ST-82-ADM-276
Equations of Motion Software Technical Memo	28 FEB 83	SI-83-ADM-075
Top Level Theory for URT Conversion	28 FEB 83	SI-83-ADM-077
FCL Software Documentation	30 APR 83	SI-83-ADM-151
Technical Memo for MWE/MWR Software	30 APR 83	SI-83-ADM-148
Stair Step Incorporation Technical Memo	31 MAY 83	SI-83-ADM-171
FCL Software Documentation (update)	31 MAY 83	SI-83-ADM-164

Table 1.4-1(d) Documentation Summary [illegible]

Document Title	Delivery Date	Comments
Redundancy Management Software Documentation (update)	23 JUN 83	SI-83-ADM-223
Redundancy Management Technical Memo	07 JUL 83	SI-83-ADM-281
FCL Software Documentation (update)	29 JUL 83	SI-83-ADM-292
JOVIAL Flight Control Law Software Documentation (2 volumes)	30 SEP 83	SI-83-ADM-344
Quad Channel Modifications of Equations of Motion Software Technical Memo	04 OCT 83	SI-83-ADM-345
JOVIAL Flight Control Software (update)	30 NOV 83	SI-83-ADM-377
Final Technical Report	31 DEC 83	SI-83-ADM-387

Table 1.4-1(b) Documentation Summary - AFTI/F-16

Document Title	Delivery Date	Comments
Software Tracking Plan	12 Feb 80	SCT-AFTI-26
Review of System Test Plan, Doc. No. 20PP003C	15 Feb 80	SCT-AFTI-27
FLCC Flyable H/W Design Review Report	22 Feb 80	SCT-AFTI-28
S/W Development Status Summary	28 Feb 80	SCT-AFTI-29 (Rev.)
Review of Flight Control Computer Documentation	22 Feb 80	SCT-AFTI-30
Review of Document: "Preliminary Software V&V Plan for System-Level Testing of the FCS OFP" (CDRL 1046)	31 Mar 80	SCT-AFTI-31
Identification of DFCS Design Issues and Documentation as of 3/27/80	31 Mar 80	AFTI-32
Review of Critical Item Development Spec for IFFC Processor	31 Mar 80	AFTI-33
DFCS Emulation	31 Mar 80	Briefing Material
Reliability Analysis	31 Mar 80	Briefing Material
Organization of AFTI Documentation	31 Mar 80	AFTI TM 80-8
Review of AFTI-16 Flight Control Computer Documentation	31 Mar 80	AFTI TM 80-7
IBU Modeling Effort	31 Mar 80	AFTI TM 80-9

Table 1.4-1(b) Documentation Summary - AFTI/F-16 (Cont.)

Document Title	Delivery Date	Comments
IBU Modeling Effort	31 Mar 80	AFTI TM 80-10
Input to NASA Monthly Report	31 Mar 80	AFTI TM 80-11
Review of Preliminary Software V&V Plan for System-Level Testing of FCS OFP	31 Mar 80	AFTI TM 80-4
Expansion of ETSE Capabilities	30 Apr 80	SCT-AFTI-37
DFCS Mechanization Document Review	30 Apr 80	SCT-AFTI-37
AMUX Bus Analysis	30 Apr 80	SCT-AFTI-38
AMUX Bus Traffic Analysis	30 Apr 80	SCT-AFTI-39
DFCS CDR Report	30 May 80	SCT-AFTI-41
DFCS Emulator Ability to Address Design Issues	30 May 80	SCT-AFTI-42
AMUX Bus Traffic Analysis	30 May 80	SCT-AFTI-39
DFCS Simulator (Emulator) Development Plan	30 Jun 80	SCT-AFTI-44
Deficiencies Uncovered by The Generic Simulator	31 Jul 80	SCT-AFTI-46
AFTI/F-16 Generic Simulator Reduncancy Management Analysis	31 Jul 80	SCT-AFTI-47
Generic Simulator: Philosophy, Benefits, and Development Schedule	31 Jul 80	SCT-AFTI-48

Table 1.4-1(b) Documentation Summary - AFTI/F-16 (Cont.)

Document Title	Delivery Date	Comments
Comments on Computer Program Development Plan (IFFC) 20PP004-3, 9 Oct 80	12 Oct 80	SCT-AFTI-61
Comments on IFFC System Design Review	17 Nov 80	SCT-AFTI-64
Comments on the S/W V&V Plan for FCS OFP	24 Nov 80	Technical Memo
IFFC System Design Review	16 Dec 80	SCT-AFTI-67
Comments on Avionics Demo Book 20PP045	19 Dec 80	SCT-FTD80-110
Test Software Mechanization	18 Dec 80	SCT-AFTI-66
Review of Integrated V&V Testing for Avionics	21 Jan 81	SCT-AFTI-71
Low-Level Tests with Fully Integrated OFP	20 Jan 81	SCT-AFTI-73
Resolution of Anomolies Found by OFCS Emulator	02 Feb 81	SCT-AFTI-74
AFTI/F-16 Coded Aerodynamics Model	22 Jan 81	FTD81-128
Comments on Procedure for the Integrated System Testing of the FCS OFP, 15 Dec 80	11 Feb 81	Technical Memo
AFTI/F-16 List of Acronyms and Abbreviations	03 Mar 81	SCT-AFTI-79

Table 1.4-1(b) Documentation Summary - AFTI/F-16 (Cont.)

Document Title	Delivery Date	Comments
NASA/Edwards Trip Report for week of 8-13 Feb 81	23 Feb 81	Trip Report
AFTI/F-16 Planning and Coordination Meetings at G.D. 28-30 Jan 81	--	Trip Report
Control Law Logic	04 Mar 81	Technical Memo
Review of G.D. Document 20PP035, Software V&V Test Plan for AFTI/F-16 SMS Operational Flight Program	16 Mar 81	SCT-AFTI-83
Sequential Data Link Receiver Failures	11 Mar 81	SCT-AFTI-82
Review of Software V&V Test Procedure	24 Apr 81	SCT-AFTI-90
Test Coverage and Unit Level Tests	06 May 81	SCT-AFTI-93
Dual Failures on the FMS Emulator	08 May 81	SCI Technical Memo
Comments on Preliminary Control Mode Selection & Transportation Response Procedures for Stand-Alone V&V Testing	30 Jun 81	SCI Technical Memo
AFTI/F-16 Aerodynamic Verification Process	02-Jul 81	SCI Technical Report

Table 1.4-1(b) Documentation Summary - AFTI/F-16 (Cont.)

Document Title	Delivery Date	Comments
Review of Procedures for Integrated System Testing of the FCS OFP	31 Jul 81	SCI Technical Paper
Plans and Instructions for a Software Audit for AFTI/F-16 Aircraft (Phase I)	25 Jan 82	Technical Report
Integrated System V&V Plan for AFTI/F-16 AMAS	01 Aug 83	AFTI Memo 204, FTD83-478
AFTI/F-16 Analysis	31 Jul 83	AFTI Report #208

Table 1.4-1(c) Documentation Summary - TRACS

Document Title	Delivery Date	Comments
DFGS Performance Analysis	30 May 80	Technical Memo
DFGS Lateral Stabilization Analysis	31 Jul 80	Technical Memo
DFGS Software Documentation	30 SEP 80	Technical Memo
Speckled Trout Flight Test Requirements	31 Oct 80	Technical Report
Speckled Trout DFGS Auto-throttle Analysis	31 Dec 80	Technical Report
Simulation Validation Facility Development	30 Sep 81	Interim Report, (Task 3.2.3)

Table 1.4-1(d) Documentation Summary - FCDL

Document Title	Delivery Date	Comments
Configuration Management Tools	31 Mar 80	SCT-SWMM-01
Requirements for a Software Management Methodology for the FCDL	31 Mar 80	Outline
Software Management Tools	08 May 80	SCT-FCDL-08
Configuration Management/ Software	08 May 80	SCT-FCDL-05
FCDL Practices and Procedures	08 May 80	SCT-FCDL-06
Software Management Methodology Requirements Analysis	10 Jun 80	SCT-FCDL-09
FCDL S/W Management Methodology Requirements Review	26 Jun 80	Briefing Charts
Software Requirements Review Comments	27 & 30 Jun 80	SCT Internal Memos
FCDL S/W Management Methodology Requirements Analysis	30 Jun 80	SCT-80/FCDL-09 (Rev. A)
H/W Management Methodology	30 Jun 80	SCT Technical Report
FCDL Near Term Task Plan	30 Jun 80	SCT-80/FCDL-10
FCDL Utility Routines	07 Jul 80	SCT-FTD80/FCDL-11
Software Inventory	08 Jul 80	SCT Technical Report
Software Inventory Manager Program Description	14 Jul 80	SCT-FCDL-12

Table 1.4-1(d) Documentation Summary - FCDL

Document Title	Delivery Date	Comments
FCDL Software Management Methodology Preliminary Design Review	21 Jul 80	Briefing Material
FIGD Software Inventory	09 Sep 80	Listing
FCDL Requirements Specification Documentation Standard (Draft)	30 Aug 80	Technical Report
Software Inventory Report	10 Oct 80	SCT-FCDL-17
Preparation of the Software User's Manual	31 Oct 80	Technical Memo
Preparation of the Software Version Description Document	31 Oct 80	Technical Memo
S/W Development and Test Standards (Vol. II)	15 Feb 81	Document Draft
S/W Configuration Management Standards (Vol. IV)	15 Mar 81	Document Final
S/W Documentation Standards (Vol. III)	23 Mar 81	Document Final
Computer Program Library (CPL) Catalog S/W Requirements Specification	23 Mar 81	Document Draft
CPL Catalog Software Requirements Specification	27 Apr 81	Technical Report
CPL Catalog Software Design Specification	08 May 81	Technical Report

Table 1.4-1(d) Documentation Summary - [illegible]

Document Title	Delivery Date	Comments
Computer Program Library Catalog Software Design	08 May 82	Specification
DTP Preliminary Design Document	05 Aug 82	Document
DTP Preliminary Design Document	05 Sep 82	Document
DTP Test Document	30 Sep 82	Document
DTP Operating Instructions	30 Sep 82	Specifications
DTP Software Design Document	30 Sep 82	Document

Table 1.4-1(e) Documentation Summary - Control System Analysis

Document Title	Delivery Date	Comments
Capabilities and Limitations of DAIS/FEF Hardware	31 Mar 80	SCT-RECON-01
Outline for Reconfiguration Study, Definition Phase Report	31 Mar 80	Briefing Material
Reconfiguration Study Definition Phase Report	15 May 80	Briefing Material
Capabilities and Limitations of DAIS/FEF Hardware (review)	15 May 80	SCT-RECON-02
Reconfiguration Study Laboratory Description Document	30 May 80	SCT Technical Report
Partitioning and Timing Control of the Reconfiguration Study Laboratory Configuration	15 Jul 80	
RECON Simulation Tool	18 Sep 80	Technical Memo FTD80-51
The Effect of Timing Control on the Reconfiguration Study Laboratory Configuration	31 Oct 80	Technical Memo FTD80-91
Reconfiguration Study Technical Briefing & Demonstration	03 Dec 80	Briefing Material
Reconfiguration Study	04 Apr 81	Interim Report
Active Wing Shape Control System Design - Program Review	18 Jun 80	Briefing Material
Active Wingshape Control System Feasibility Design Study (Based on Modern Control Design Principles)	April 81	Draft Final Report

Table 1.4-1(e) Documentation Summary - Control System Analysis (Cont.)

Document Title	Delivery Date	Comments
FIREBOLT Interim Report	30 Oct 81	Technical Report
User's Guide for the High Altitude Supersonic Target FIREBOLT Simulation	--	Technical Report
Engineering Analysis of the FIREBOLT Flight Control System, Simulation Update and Flight Test Support	26 Oct 8[illegible]	Technical Report

Table 1.4-1(f) Documentation Summary - Control/Display Development

Document Title	Delivery Date	Comments
Stand-Alone Test and Verification of the MLS Program	30 Jun 80	STI-80-SAD-094
Microwave Landing System S/W Computer Program Product Specification	29 Dec 80	STI-80-OPR-084
Requirements of Synthetic Terrain Expanded Capability	09 Feb 81	Technical Memo
Real-Time Synthetic Terrain System Analysis	31 Mar 81	Technical Memo
Floating Point System Configuration	20 Mar 81	Technical Report
Real-Time Synthetic Terrain Systems Analysis Task 3 Synopsis: Computational Aspects	12 May 81	SCT-FTD81-184
Graphic System Attributes	10 Apr 81	Technical Paper
Benchmark Program	19 May 81	Technical Paper
Real-Time Synthetic Terrain Systems Analysis Task 4 Synopsis	20 May 81	Technical Report
Processor Benchmark	02 Jul 81	Report Paper
Graphics Benchmark	08 Jun 81	Technical Report
Synthetic Terrain Expanded Capability Analysis	31 Jul 81	Draft Technical Report

Table 1.4-1.(f) Documentation Summary - Control/Display Development (Cont.)

Document Title	Delivery Date	Comments
Protocol Recommendation for Flat Panel Display	03 Aug 81	SCI Memo FTD81-128
Protocol Questions and Recommendations	31 Jul 81	Technical Report
DIGISYN S/W Reconfiguration Recommendations	28 Jul 81	Technical Report
Timing Analysis for Flat Panel Software Tasks	14 Aug 81	SCI Memo FTD81-220
Communication Protocol Recommendation for the Flat Panel Display Interface to Host Computer	14 Aug 81	SCI Memo FTD81-221
MMMD Litton Protocol Document Revision Comments	04 Nov 81	SCT Memo FTD81-255
Transmittal of [illegible] Input/Output Driver Software	12 Oct 81	Technical Memo
Summary of Voice/Stores Demo Requirements	05 Jan 82	SCT Memo FTD82-276
SFAM S/W Requirements	1i Mar 82	SCT Memo FTD82-288
[illegible]-F Input Access and Distribution S/W: Description and User's Manual	15 Apr 82	Document
Speech Application to Multi-function Control S/W Modification Description Document	26 Apr 82	Document

Table 1.4-1(f) Documentation Summary - Control/Display Development (Cont).

Document Title	Delivery Date	Comments
ASTEC Executive S/W, "Voice Input Processing"	May 1982	Document
DA11 Transfer Software Design Description	01 Feb 82	Document
Bowman Measurements Report	15 Mar 82	Document
Performance Measurement Variables for the MMM Study	02 Jun 82	SCT Memo FTD82-311
Data Reduction Requirements for the MMM EADI Evaluation	08 Jun 82	SCT Memo FTD82-312
MMM Experiment Test Matrix and Daily Schedule	14 Jun 82	SCT Memo FTD82-318
MMM Experiment Software Requirements	28 Jun 82	SCT Memo FTD82-324
Illuminance Measurements of Selected Color Slides Used in the Information Display Study	11 Nov 82	Technical Report
Pictorial Emergency Procedures & Speech Interaction S/W Modification Description Document	08 Jun 83	SCT Doc. No. 5336-538-2
MAGIC Aeromodel (AFLOAD) Software Overview	Sep 1983	Doc. #5336-539-1
VOTAN/Apple Pascal Interface Control S/W Design Specification	Nov 1983	Doc. #5336-539-2
MAGIC Aeromodel (AFLOAD) Software Overview	Dec 1983	Doc. #5336-539-1A

Table 1.4-1[illegible] [illegible] Summary - Control/Display Development (Cont.)

Document Title	Delivery Date	Comments
MAGIC Advanced Tracking Task (MATT) Requirement Specifications (Preliminary)	Dec 1983	Doc. #5336-539-3
VOTAN/Apple Pascal Communication S/W Description	28 Dec 83	Doc. #5336-539-4
MAGIC Data Recording Software Description	Sep 1983	Doc. #5336-540-1
MAGIC Data Reduction Software Description	Sep 1983	Doc. #5336-540-2
Modification of MAGIC Data Reduction Software	Sep 1983	SCT Memo 83-500
MMMD Formatter S/W Design Specification Change Pages	Oct 1983	Doc. #5336-542-2
Joystick Test Box Software Description	Sep 1983	Doc. #5336-542-3

Table 1.4-1(d) Documentation Summary - AFTI/F-111

Document Title	Delivery Date	Comments
AFTI/F-111 MAW CPDP Review Comments	27 Oct 80	Technical Memo FTD80-85
Comments on MAW Software Requirements Specification	18 Feb 81	Technical Memo FTD81-140
AFTI/F-111 Boeing Simulation Trip Report	06 Feb 81	Technical Memo
Comments on Boeing CPDP (Rev. A)	02 Feb 81	Technical Memo
Review on Comments S/W Requirements Specification AFTI/F-111	07 Apr 81	Technical Memo FTD81-167
MFCS Software PDR RIDs	24 Jun 81	Technical Report
AFTI/F-111 MAW CDR & AFCS PDR	23 Jul 81	SCI Memo FTD81-208
AFTI/F-111 Boeing Trip Report 15-18 Sep 1981	22 Sep 81	Technical Trip Report
Boeing Software Activities SCT Software Support	01 Oct 81	Technical Papers (2)
AFTI/F-111 MAW MFCS S/W CDR and AFCS Engineering PDR	23 Nov 81	SCT Memo FTD81-266
NASA AFTI/F-111 Simulation Validation	10 Dec 81	Memo Paper
AFTI/F-111 (Boeing/NASA)	12 Mar 82	Trip Report
A26-2 Aeromodel Description	26 Feb 82	Technical Paper
AFTI/F-111 Simulation Aeromodel V&V	12 Apr 82	Technical Memo

Table 1.4-1(a) Documentation Summary AFTI/F-111 (Cont.)

Document Title	Delivery Date	Comments
Comments on AFCS S/W Requirements Specification	28 Jun 82	SCT Memo FTD82-323
AFTI/F-14 MFCS S/W Review	29 Sep 82	SCT Memo FTD82-361
AFTI/F-111 MAW AFCS S/W PDR	31 Dec 82	Trip Report
Boeing AFTI/F-111 Software Development Comments	14 Jan 83	SCT Memo FTD83-397
Review of AFTI/F-111 MAW Computer Program Development Plan (Rev. D), #D365-23310-1	Dec 1982	SCT Memo FTD83-411
Review of MFCS S/W Design Description Document, #D365-10072-1	Apr 1983	Technical Memo
AFTI/F-111 Trip Report	Jun 1983	SCT Memo FTD83-461
AFTI/F-111 MAW Trip Report, 1-4 Nov 1983	18 Nov 83	SCT Memo FTD83-513
Functional Testing at NASA/Dryden AFTI/F-111 Trip Report, 9-14 Dec 1933	Dec 1983	SCT Memo FTD83-525
AFTI/F-111 MAW AFCS MCC & CCC CDR & MLC & ME/GA PDR - Trip Report 9-13 Jan 1984	Jan 1984	SCT Memo FTD84-530

2.1 DIGITAL SYNTHESIS FACILITY

2.1.1 Facility Background and Goals

The Digital Synthesis Facility (DIGISYN) was developed in early 1974 as an outgrowth of the DAIS program. This program exercised on-flight processors in a real-time simulation environment. The Flight Dynamics Laboratory decided to utilize this concept to test actual flight control system performance and pilot-in-the-loop response. DIGISYN was established to analyze the application of avionics military standards to digital flight control technology. Some of the military standards to be analyzed recently within DIGISYN are the 1553 aircraft multiplex bus data standard, the 1750 minicomputer instruction set architecture standard,and the 1589 JOVIAL higher order language standard. In addition, flight safety, various architectures, and integrated systems issues have been investigated.

Figure 2-1 presents the major milestones accomplished by DIGISYN since 1974. Recent highlights include the design and development of a flight control specification in JOVIAL in February 1980; the integration and validation of a single remote terminal/flight control/equations of motion system in February 1981; the integration of a simplex flight control system in May 1982; and the integration of a quad redundant flight control system in November 1982. (The quad redundant FCS did not operate correctly, due to unresolved hardware and software problems).

2.1.2 Facility Description

The DIGISYN, shown in Figure 2-2, comprises four PDP-11s; a

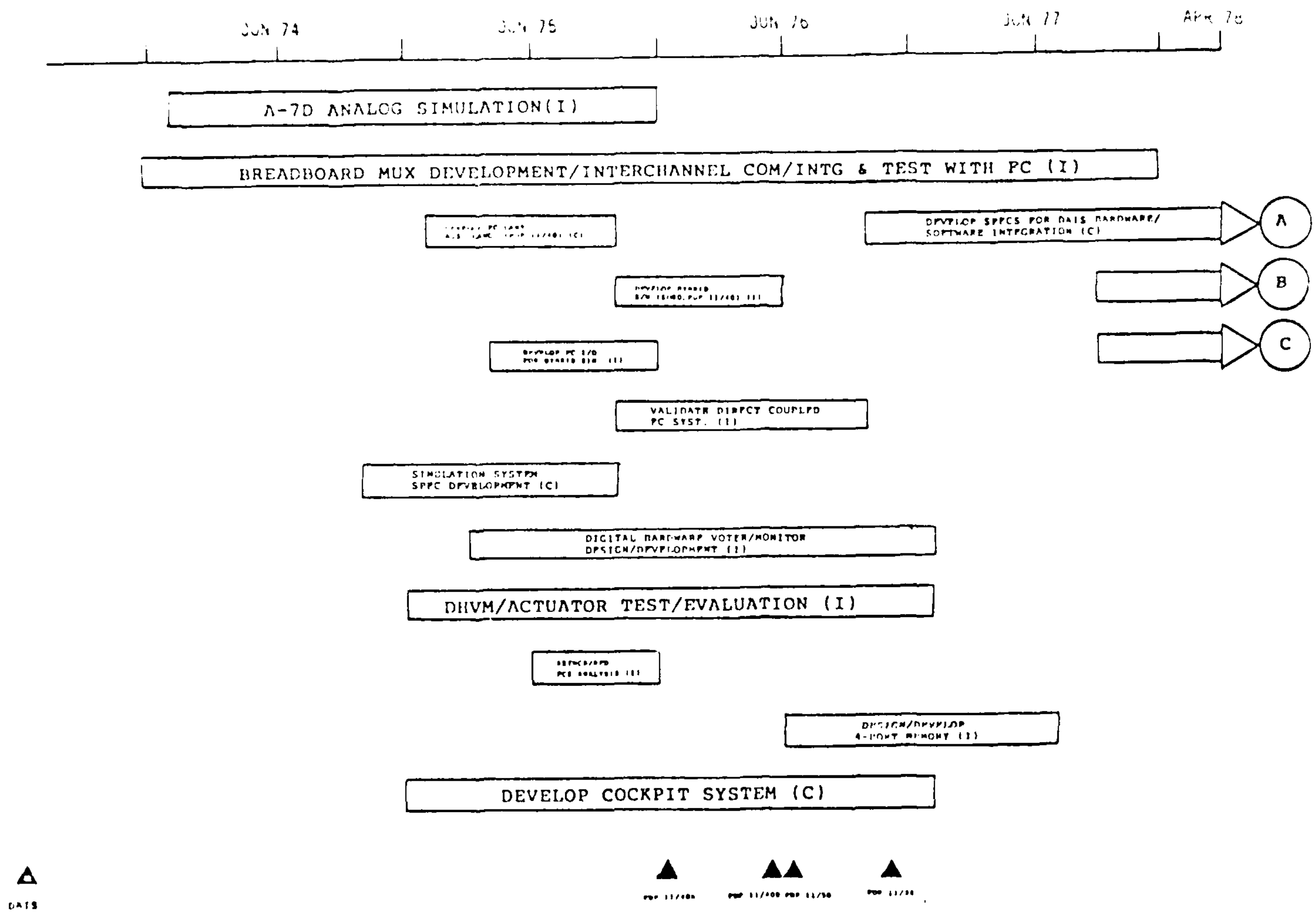


Figure 2-1 Major Milestones Accomplished by DIGISYN
(Sheet 1 of 2)

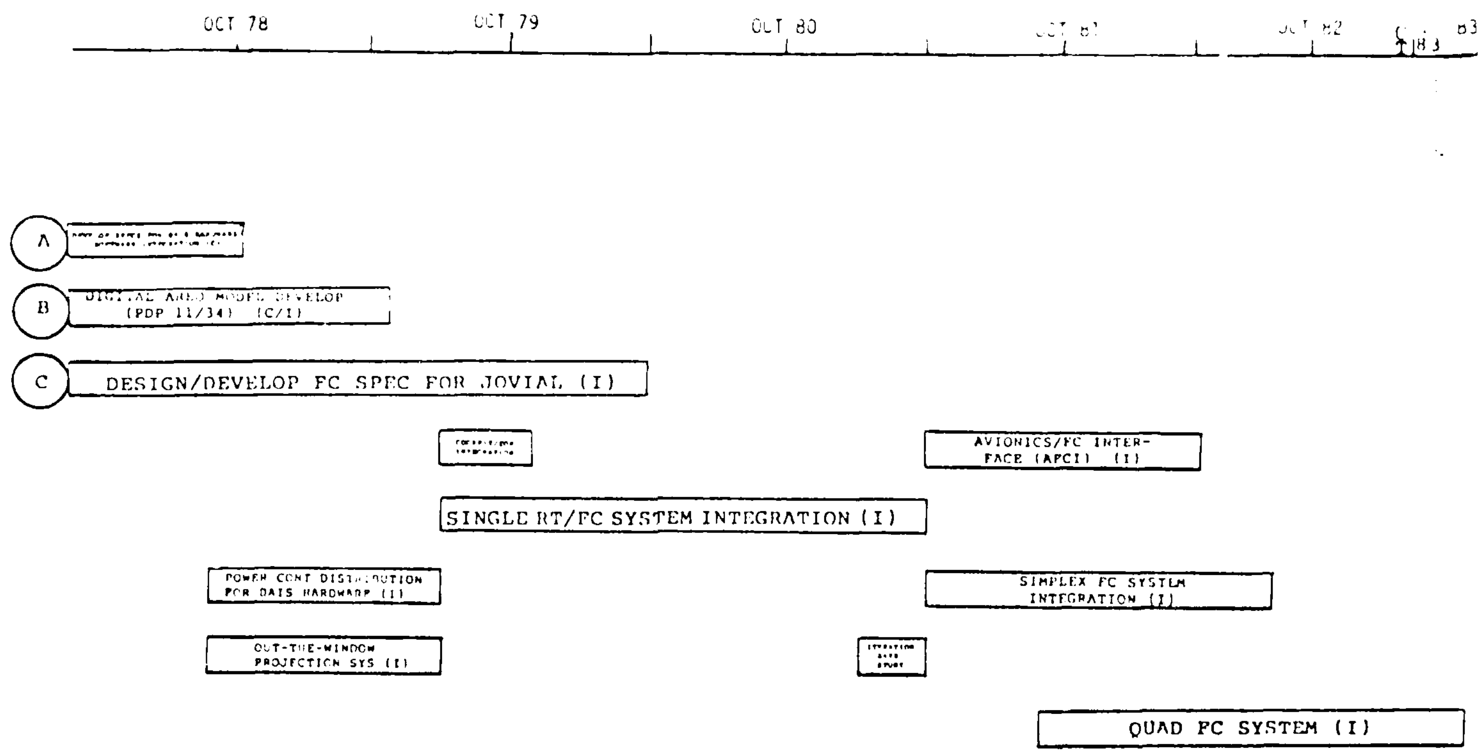


Figure 2-1 Major Milestones Accomplished by DIGISYN
(Sheet 2 of 2)

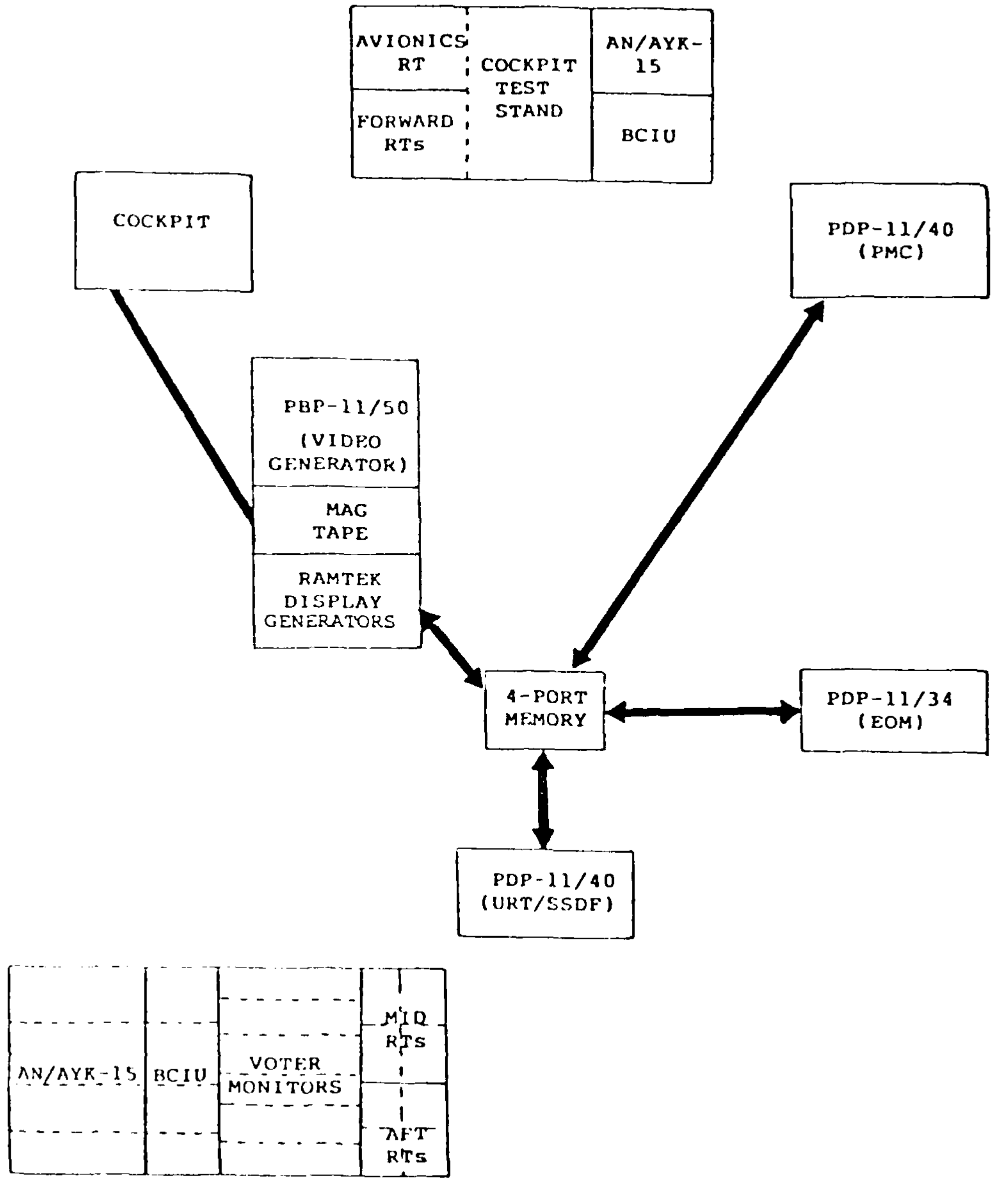

AVIONICS RT
FORWARD RTs
COCKPIT TEST STAND
AN/AYK-15
BCIU
COCKPIT
PDP-11/40 (PMC)
PBP-11/50 (VIDEO GENERATOR)
MAG TAPE
RAMTEK DISPLAY GENERATORS
4-PORT MEMORY
PDP-11/34 (EOM)
PDP-11/40 (URT/SSDF)
AN/AYK-15
BCIU
VOTER MONITORS
MID RTs
AFT RTs

Figure 2-2

rack of aircraft processors containing a quad system of AN/AYK-15s, Bus Control Interface Units (BCIUs), Voter Monitors, Midship Remote Terminals (RTs), and Aft RTs; a mock cockpit facility for testing pilot-in-the-loop responses and a rack containing the avionics AN/AYK-15 and BCIU, the avionics RT, the forward RTs, and a cockpit test stand.

DIGISYN has developed a quad-channel flight control system which utilizes the hardware components. Figure 2-3 presents the quad channel system and the hardware interfaces between the components.

2.1.3 Facility Plans

DIGISYN recognized the need for a high-level integration program utilizing a real-time simulation test bed. Of fundamental concern to the organization were flight control systems, pursuit of new architectures and the evaluation of military standards.

The plan was to acquire the hardware and software necessary to perform the evaluations and document the results.

2.1.4 Work Accomplished

For the duration of the contract, tasks were performed following the facility plan. These tasks can be broken down into the areas of support software (drivers, interfaces, corrections), flight processor development (incorporation of new hardware), concept test support (simple versus full redundancy management), integration and validation support (flight control/equations of motion), experiment support (iteration rate study), and software documentation.

2.1.4.1 Support Software Development

A variety of tasks were accomplished under this heading. All Equations of Motion (EOM) software modifications were considered support software since the initial software was already written and documented at the inception of this contract. Those tasks performed

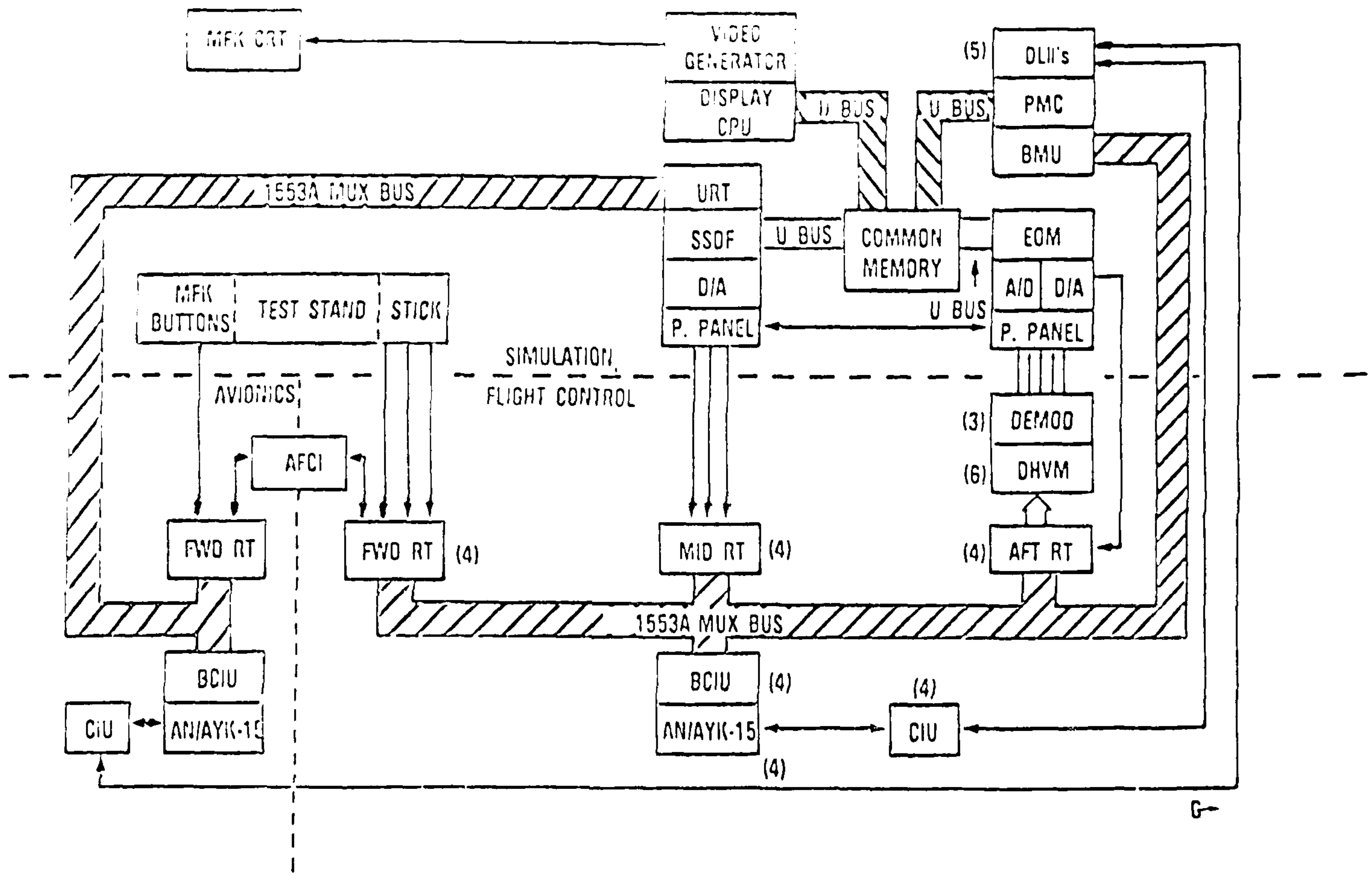


Figure 2-3 Quad-Channel Flight Control System

were:

- Designed and devloped an EOM/terrain board interface driver to allow the real-time control of the terrain board cameras as well as the protocol and handshake functions.
- Adjustment of scale factors to decrease the number of arithmetic overflows.
- Implemented a programmable function generator which can produce a step, doublet, or square waveform of selectable amplitude and frequency.
- Correction of the EOM display page 4 time overflow problem.
- Modified the EOM software to output all variables to the flight control laws at an 80 Hertz rate.
- EOM 4-Port Memory Incorporation--This task has not been completed. Many problems have been identified and corrected but the 4-port memory is still not operational. A simple driver to handle the 4-port memory based on a working RT-11 version was not completed at the end of this contract.
- Performed an EOM global variable analysis, which identified all source files in the EOM, the names of subroutines invoked, the read/write access type of all global variables and a list of the general registers and their access type.
- Added the necessary software to incorporate the quad channel A/D software.

Additional support tasks were to:

- Provide file transfer capability from the DECsystem-10 to the DIGISYN PDP 11/40 processor. This involved software and hardware verification.
- Provide a software and documentation configuration control plan for DIGISYN which includes resource control for disks and tapes and disk maintenance procedures.

- Reconfigure and rebuild the RSX-11M system disk, whenever necessary (such as bad block detection, new hardware, etc.).
- Design of a Performance, Monitor and Control (PMC) system for the PDP-11/40 for evaluation of the single channel flight control system.
- Convert URT software to RSX-11M. This conversion involved a new sysgen, the definition of the URT software to be converted, investigation of handling interrupt processing, virtual address conversion to a physical address, and a new display format.

2.1.4.2 Flight Processor Computer Program Development

This area encompasses all the software written to be run on the AN/AYK-15s. The original flight control laws for the A-7D were written at the inception of this contract. Their validation is referred to in Section 2.1.4.4. Tasks performed were:

- IBM/BCIU Design and Development--This software provided an interface between the AN/AYK-15 processors and the BCIU in the DAIS interface format. All handshake and scheduling operations were also controlled.
- Developed a library of I/O routines using JOVIAl (BCIU, AN/AYK-15 and RT, initialization, conversion of decimal to binary, conversion of binary data to hexadecimal, character string handler).
- Redundancy Management (RM) Software Design and Development--This software was designed to handle failed signals and permit pilot recycling.
- Correct the Iteration Rate--The flight control law (FCL) software was determined to be running at an 8-Hertz rate instead of the correct 80-Hertz rate.
- Power-Down/Power-Up Capability--Software was written to enable recoverability of the AN/AYK-15 software after a Power-Down/Power-Up sequence.

- COMPOOL Incorporation--The JOVIAL software was reorganized to utilize the COMPOOL features of JOVIAL.
- New Mux Driver Design and Development--This software incorporated a three remote terminal system as well as a serial activity processor module.
- Forward RT Incorporation--The JOVIAL software was modified to accept input data from the forward RT.
- Mid RT Incorporation--The JOVIAL software was modified to accept input data from the mid RT.
- Voter/Monitor Incorporation--The JOVIAL software was modified to utilize the hardware voter/monitors when outputting data to the EOM.
- Mode Switch Selection Incorporation--The JOVIAL software was modified to allow a switch depression from the multi-function keyboard (MFK) to be read by the avionics RT and passed via the AFCI to the AN/AYK-15.
- Channel Selection Incorporation--The JOVIAL software was modified to allow selection of either single- or quad-channel output processing.

- Stair Step for Single Channel--The JOVIAL software was modified to output increasing values ranging from -1024 to 1024 for each minor frame in place of the old sync signal. This allowed quick visual verification on the strip chart recorder that the minor frame software was being executed.
- J73/I to JOVIAL Conversion--The J73/I software was converted to use the JOVIAL compiler which is the MIL-STD-1589B implementation.

2.1.4.3 Concept Test Support

Tasks in this area are those which were performed to evaluate a theory or concept; i.e., will this idea work and the software still be able to run an 80 Hertz rate?

- Integrate a Flight Control Skew Control Unit (FSCU), a Simulation Subsystem Integration Unit (SSIU), and a Bus Monitor Unit (BMU) to provide the capability to evaluate the operation of a quad-redundant, asynchronous flight control system. The FSCU controls the timing of the flight control processors for the escalation of the effect of asynchronous operation on redundancy management and system reliability. The SSIU provides quad-redundant sensor inputs to the processors through the RTs.
- A simplified redundancy management module was written and incorporated into the Flight Control Law software. A simplified version was selected to be integrated to ensure that there would be no timing problems in the AN/AYK-15.
- A full redundancy management module was written and incorporated into the Flight Control Law software. This version is based on the design by Dr. Charles Slivinsky.

2.1.4.4 Integration and Validation Support

The tasks in this area integrated the various subsystems (flight (control and EOM) and then validated the results.

- Hardware interface verification between the AN/AYK-15 and the PDP-11/34. This involved testing and verification of all scale factors.
- A trace procedure was written and coded to aid in integration.
- Stand-Alone validation of the single-channel Flight Control Law Software (FCLSW) where test procedures were developed and executed. Results were then validated based on predicted outcomes (see Figure 2-4)
- Static checkout of the single FCLSW and the EOM, which involved running both systems and verifying that

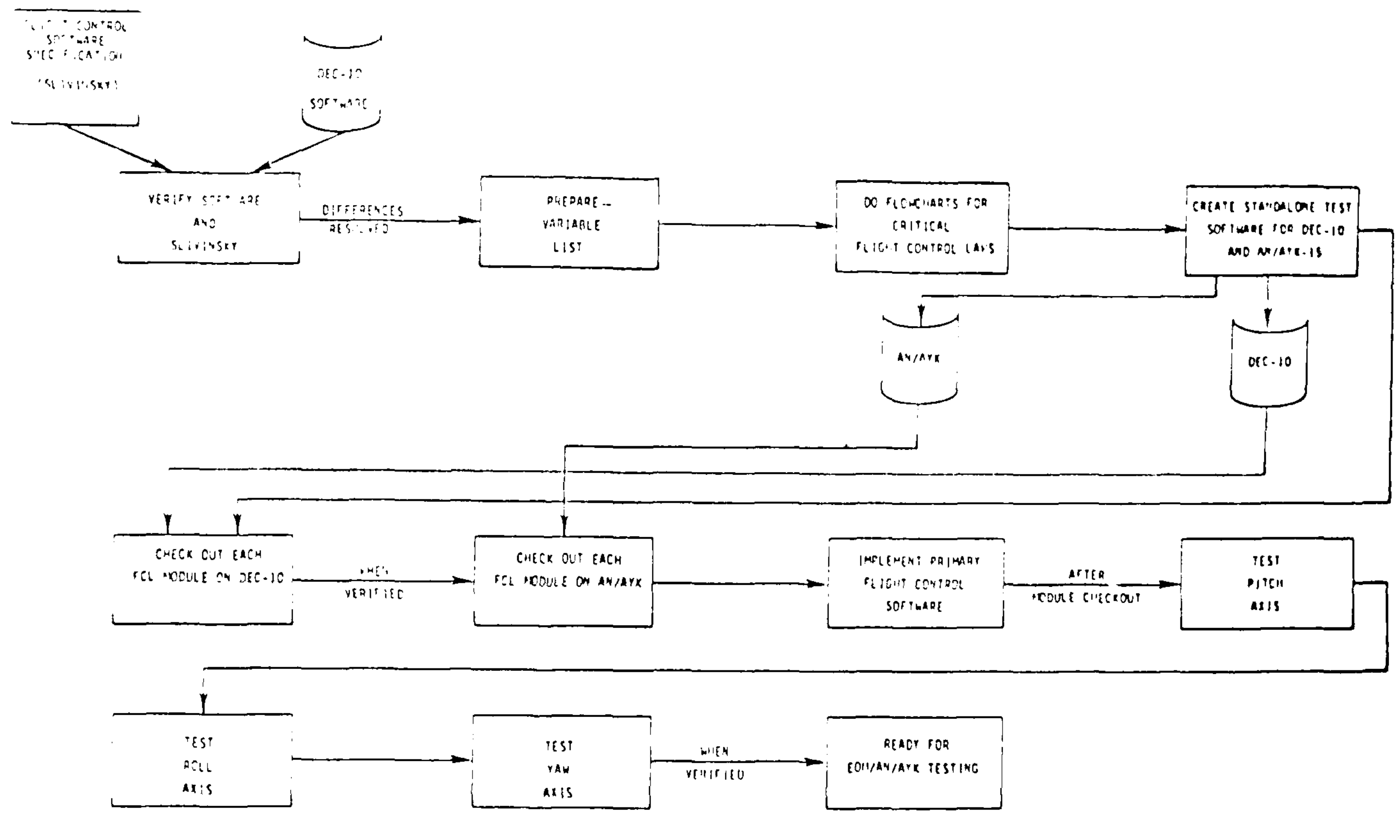


Figure 2-4 Single Channel FCLSW Validation

conditions remained stable.

- Dynamic checkout of the single channel FCLSW and the EOM, which involved running both systems with various input signals and then validating results (see Figure 2-5)
- Rehost of Avionics Laboratory diagnostics software for the RTs, URT, and BMU to the DIGISYN processor.
- Static Checkout of the quad-channel FCLSW and the EOM. The tests conducted were a subset of those run for the single-channel static checkout. All flight control RTs were utilized as well as the avionics RT.
- Dynamic checkout of the quad-channel FCLSW and the EOM. Again the tests conducted were a subset of those run for the single-channel dynamic checkout.

2.1.4.5 Experiment Support

Once the hardware and software for the single-channel system was validated, various experiments were designed and discussed as to their flight control and/or military standard significance. After it was determined which experiments were to be performed, software was written and hardware developed as necessary, to record the results.

2.1.4.5.1 Skew Studies

The Flight Control Law/EOM Processor Skew Studies investigated the effect of varying the skew between the EOM Processor and the AN/AYK-15. The objective was to determine the impact, if any, of processor skew (asynchronism) on the integrety of bus transmissions and flight control law performance. This experiment was an essential step in the Digital Synthesis facility development since the concept of quad redundant AN/AYK-15s rely on asynchronous operation.

Experiment support involved the establishment of a synchronization line between the AN/AYK-15 and the PDP-11/34 and the development of a hardware board to bias the clocks between the two processors.

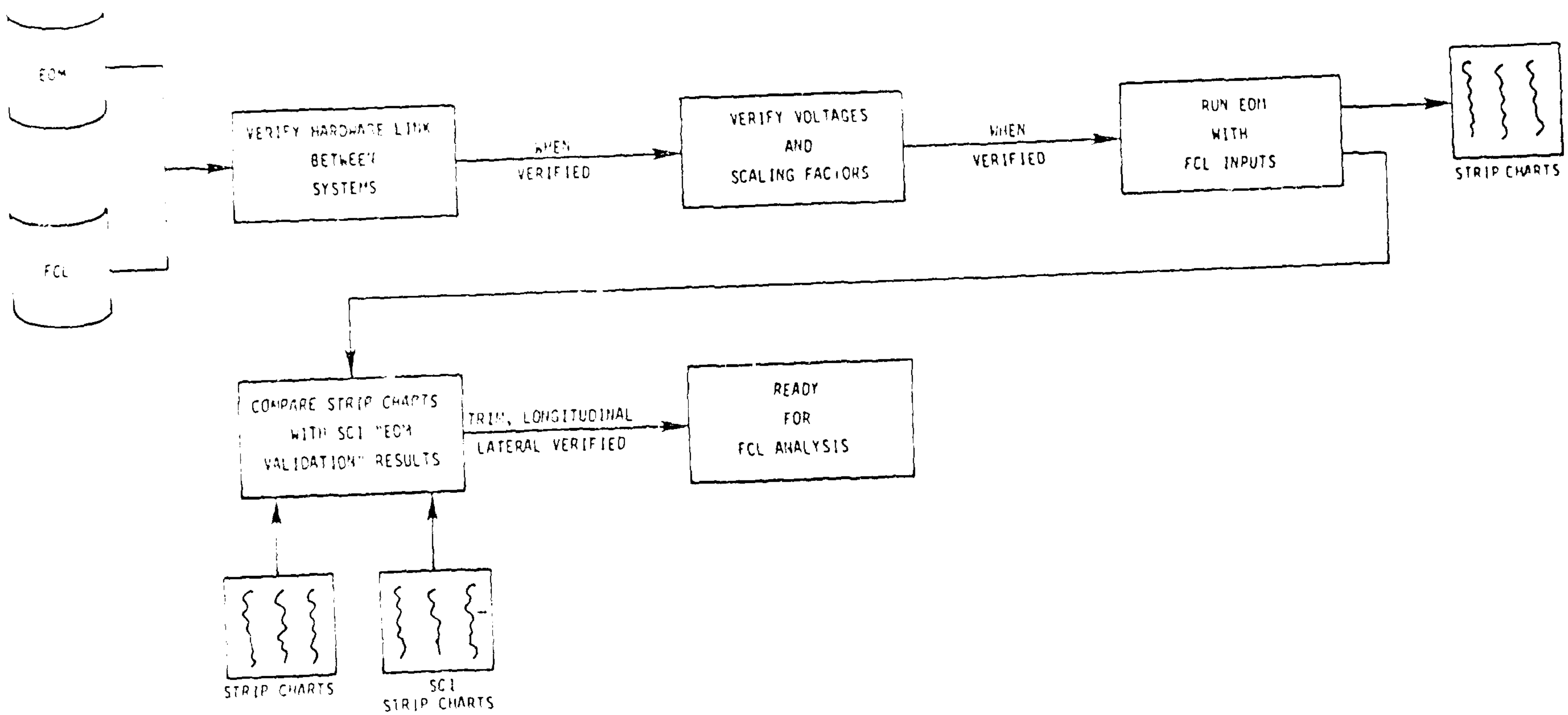


Figure 2-5 Dynamic Single-Channel FCLSW Validation

2.1.4.5.2 Iteration Rate Studies

The processor iteration rate studies investigated the effect of varying the iteration rates of both the flight control laws (AN/AYK-15) and the EOM (PDP-11/34). The objective was to determine the impact on control law performance. This experiment provided information on any spare time available to accommodate any additional code. It also provided information as to how much faster the EOM must be executed relative to the control laws so as to appear "continuous" to the asynchronous sampling channels.

Experiment support involved developing software to measure spare duty cycle and execution times for various phases of control law processing.

2.1.4.6 Software Development and Documentation Summary

Table 2-1 summarizes the software development efforts undertaken over the duration of the Integrated Control System Engineering Support contract.

2.1.5 Technology Assessment

2.1.5.1 Flight Control Issues

Since the objective of DIGISYN is to evaluate military standards as they apply to digital flight control technology, the following issues were identified as worthy of investigation:

Standardization of Hardware and Software Modules

- Evaluate feasibility of standardizing hardware and software.
- Evaluate to what degree differing requirements could result in the same modules not being satisfactory for both flight control and avionics functions.

Table 2-1 Documentation Summary

Software Effort	Duration	Comments	Task Number
EOM/Terrain Board Driver	09/79--03/80	Included Diagnostic Software	1.1.1
DEC-10 File Transfer	10/79--12/79	Corrected Existing Software and Hardware	1.1.2
BCIU Driver Software	10/79--02/80	Software Interface to Conform to DAIS Interface control Document Included I/O Library	1.2.1
Software Configuration Control	01/80--07/80	Develop a Configuration Control Plan for DIGISYN	1.1.4
Asynchronous Operation Evaluation	02/80--09/80	Software for: Skew Control Unit Subsystem Interface Unit Bus Monitor Unit Performance Monitor and Control System	1.1.5
Redundancy Management	02/80--06/80		1.2.2
General Integration Support	12/79--12/83		1.4.2
Demonstrate Configuration A1	10/80--12/80	Included Skew Study	1.4.2.1
Demonstrate Configuration A2	12/80--02/81		1.4.2.2
Iteration Rate Study	03/81--04/81		1.4.2.3

Table 7.1 Documentation Summary (Concluded)

Software Effort	Duration	Comments	Task Number
Software Support	04/81--09/81	4-Port Memory	1.4.2.7
		Power Down/Power Up	
		COMPOOL Incorporation	
Software Support	10/81--12/83	New Mux Driver	1.4.3
		Forward RT Incorporation	
		Mid RT Incorporation	
		Voter/Monitor Incorporation	
		Simple Redundancy Management	
		Mode Switch Selection	
		Channel Selection Incorporation	
		4-Port Memory	
		EOM Quad Channel Incorporation	
		Stair Step for Single Channel	
		J73I to JOVIAL Conversion	
EOM Global Variable Analysis	05/82--06/82		1.4.6
URT Converstion	08/82--10/83	RSX-11M Sysgen	1.4.7
		Definition of URT Software	

Multiplex

- Verification of flight control performance with a MIL-STD-1553A multiplex data bus.
- Investigate potential problems with latent, single-point or propagated failures.
- Investigate efficiency of information transfer.
- Evaluate ease-of-reconfiguration.
- Investigate self-test capabilities, reliability, failure isolation, optimal modular construction, bus/bus interface problems, and electromagnetic interference susceptibility.
- Study multiplex bus loading requirements.

Flight Control Software

- Demonstrate efficiencies of modular software and higher order language.
- Evaluate trade-offs for various executive structures.
- Evaluate time/memory trade-offs of macrostatements versus subroutines.
- Evaluate to what extent higher order language is feasible.
- Investigate which commands/instructions in JOVIAL are not acceptable for flight control.
- Evaluate improvements in development time expected for changes and new applications with modular software.
- Investigate methods for avoiding single-point software failures.
- Investigate adequacy of the compiler with respect to efficiency and error processing.
- Evaluate performance penalties and improvements resulting from use of AN/AYK-15 processors.
- Evaluate what hardware fatures of AN/AYK-15 are most beneficial for flight control.
- Evaluate the extent of performance degradation resulting from digitization of control laws.

2.1.5.2 Analysis and Equipment Recommendations

2.1.5.2.1 Demo Al Synchronizing Implementation Test

The Demo Al Synchronizing Implementation Test demonstrated that the Flight Control Laws (FCL) on the AN/AYK-15 and the Equations of Motion (EOM) on the PDP-11/34 (see Figure 2-6) are synchronized together and can be skewed relative to each other by as much as 12.5 msec The AN/AYK-15 processor is the controlling device.

The primary objective of this test was to demonstrate the following functional capabilites:

- Provide synchronization between the FCL and EOM utilizing a spare D/A output channel on the RT.
- Provide software programmable skew control between the FCL and the EOM.
- Provide asynchronous operation of the EOM relative to the FCL, utilizing the PDP-11/34 initial clock.

Test #1 was conducted with no skewing, and there was an approximate 12.5 msec delay due to the EOM execution time. Consequently, the EOM was half a cycle behind the FCL. This situation was remedied by having the AN/AYK-15 send the pitch, roll, and yaw displacements first, and the sync signal last. In this manner, the EOM already had the FCL outputs when the sync signal arrives. Also in Test #1 we noted that PITDSP does lag PSFAV by approximately 5 msec. We also observed that all EOM outputs lag PITDSP (EOM input) by a certain amount of time. The delay is due to EOM execution time in combination with a programmed Ø.Ø5 second lag although PITDSP is in sync.

Test #2 was performed with the addition of a skew (time delay) to the received EOM SYNC signal of 12.5 msec (maximum delay). In combination with the 12.5 msec delay due to the EOM execution time, the signal response should have been, and was, 25 msec. PITDSP was still in sync, just as it was in Test #1.

Test #3 graphically showed that when the FCL is halted, the EOM

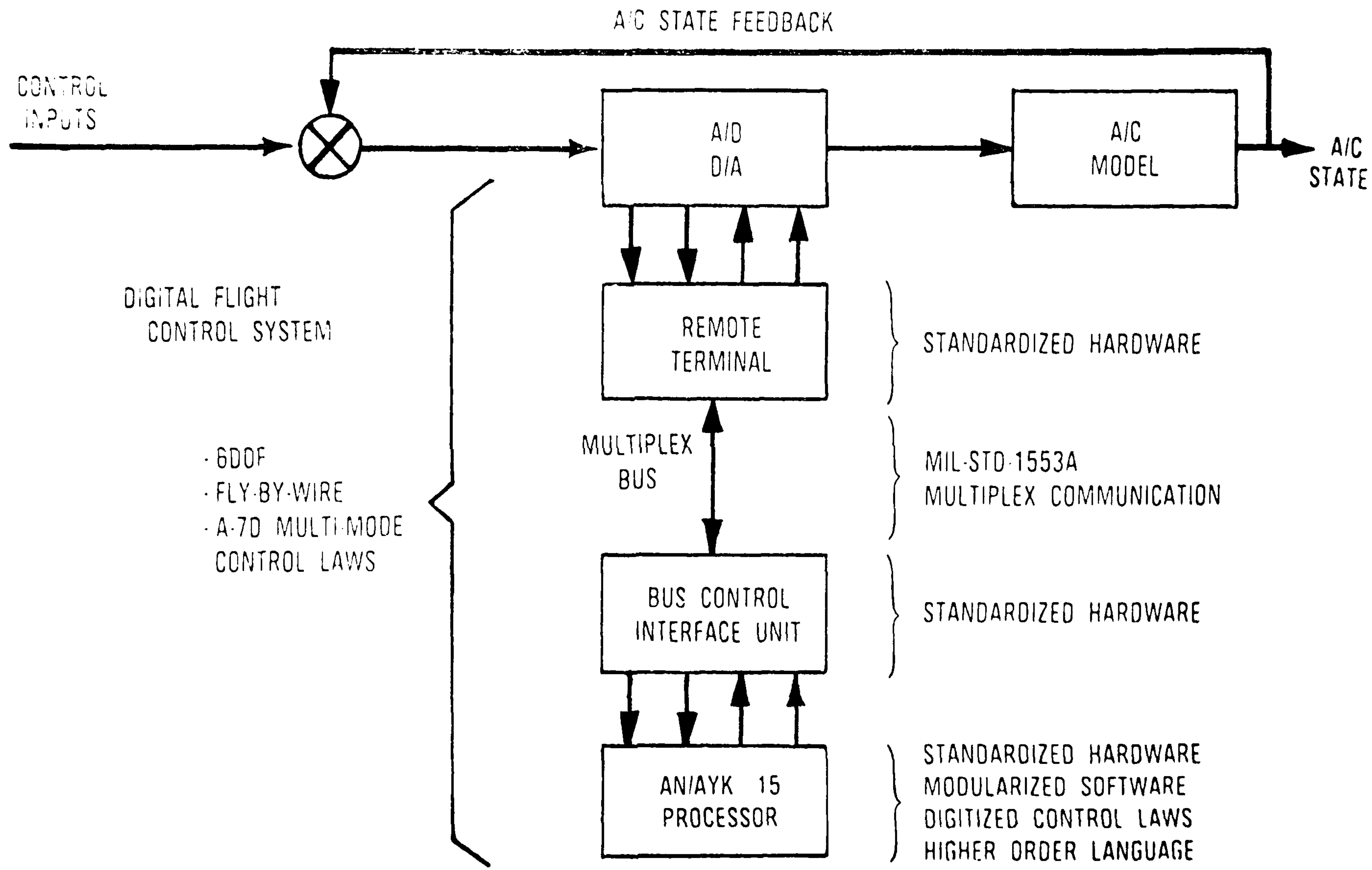


Figure 2-6 Austere Single Channel Flight Control Simulation - Issues

is halted due to lack of sync signal.

In conclusion, all of the test objectives of Demo A1 were achieved. The only inconsistency between the predefined test objectives and the results was the 12.5-msec delay due to the EOM execution time discussed above.

2.1.5.2.2 Demo A2 FCL and EOM Closure and Stability Test

The FCL and EOM Closure and Stability Test demonstrated a stable closed-loop system with the Flight Control Law (FCL) on the AN/AYK-15 and the equations of Motion (EOM) on the PDP-11/34. The primary objective of this test was to demonstrate the following functional capabilites:

- Stable EOM Subsystem with no integer overflows occurring
- Stable FCL Subsystem
- Stable closed-loop EOM/FCL system.

To accomplish the preceding objectives, the following test approach was used:

A. Static Test with Flight Control "off" (Demo A2.1)--The purpose of the static test was to ensure that the closed loop EOM/FCL system will maintain its stability and not drift significantly from the aircraft model trim condition when no control inputs are applied to the system. This test was conducted using data set Ø.

B. Static Test with Flight Control "on" (Demo A2.2)--This test was run to verify that the system would still maintain a relatively steady state with flight control "on".

C. General Dynamic Test (Demo A2.3)--The purpose of this dynamic test was to demonstrate that the flight control laws and the EOM both respond to pilot stick inputs in a reasonable manner.

The system configuration used for the FCL and EOM Closure and Stability Test is depicted in Figure 2-7.

Test #1 (Demo A2.1) was conducted as a static test, running

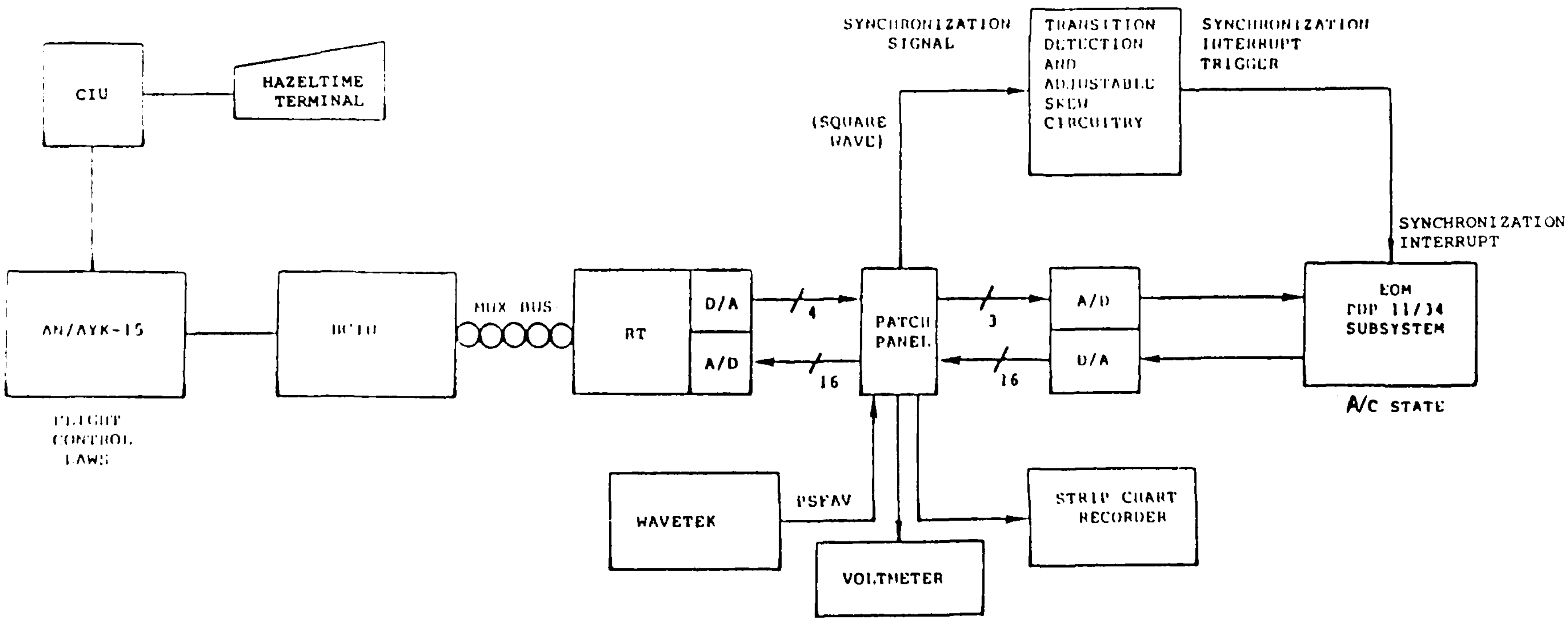


Figure 2-7 System Configuration for the Synchronizing Implementation

closed-loop with the FCL off. The test results showed that the closed-loop EOM/FCL system is stable. The pitch, roll, and yaw rates were all in the noise level about zero. Pitch altitude oscillated between 0 and 6 degrees. Roll attitudes oscillated between 0 and 1.6 degrees. The angle of attack held at a constant 4.6 degrees. The normal acceleration was in the noise level about zero. True airspeed maintained a constant 660 ft./sec.

Test #2 (Demo A2.2) was conducted as a static test, running closed-loop with the FCL on. The results showed the pitch rate oscillates between +0.4 radian/second (which is approximately 2 degrees/second) and -0.04 radian/second. Meanwhile, the roll and yaw rates were in the noise level about zero. Pitch attitude oscillated between 0 and 7.4 degrees, while roll attitude varies between 0 and 7.4 degrees. The angle of attack maintained a constant 4-degree value. The normal acceleration was in the noise level around zero, and the true airspeed varied between 680 and 760 ft./sec.

Test #3 (Demo A2.3) was conducted as a dynamic test to see if the FCL/EOM closed-loop system would indeed stabilize itself after being perturbed. The source of the perturbation for this demonstration was in the form of a 4-volt, 0.5-second input to the pitch stick channel. Since the applied stick force should only perturb the pitch axis, it would be expected that no noticable changes would occur in the roll and yaw axes parameters. This holds true for the results of our test as roll rate, yaw rate, and roll attitude do not vary at all from their timmed conditions. Also as expected, all of the pitch axis variables are affected, taking the form of a damped sine wave. Pitch rate reached a maximum value of about 0.455 radian/second (26 degrees/second) in the 0.5 second that the +12 pounds of applied pitch stick force before the dampening process begins. Pitch attitude climbed to a value of around 12.3 degrees, while the angle of attack went as high as approximately 7.5 degrees before dampening out to its trim value of 4 degrees. Normal acceleration rose as high as around 248 ft./sec2. All of the pitch axis parameters damped out to their timmed state after approximately 5 seconds.

In conclusion, all of the test objectives for Demo A2 were

achieved.

2.1.5.2.3 Verification of the Single Channel Flight Control Software

The tests required for verification and functional testing of the austere single axis flight control software were organized in a manner designed to verify the computer program, starting with the basic modules and progressing to a totally integrated functional test. The following test sequence was used:

- Executive
- I/O Scaling
- Initialization
- Mode Control
- Control Law Module Test
- Control Law Functional Tests
- Redundancy Management Tests.

The Executive tests verified timing and progam structure. The I/O scaling verified correct data tansfers between the AN/AYK-15 and the simulation processor. Initialization testing verified that the appropriate variables were properly initialized. The mode and switch logic tests were performed to verify the control panel operation and switching operations that are used by the control law modules. The control law modules were first tested individually to verify proper operation and collectively to verify functional performance. Finally, redundancy management operation was tested to verify fault detection and signal selection operation.

2.1.5.2.4 FCL Iteration Rate Study

The basic purpose of the FCL iteration rate study was to determine the impact of reduced FCL iteration rates upon the performance of the A-7D "Austere Single Channel Flight Control System." The study was to show whether or not the integrity of the simulation would be affected when lower iteration rates were implemented. Use of lower

iteration rates would result in more spare simulation time. More specifically, this FCL iteration rate study would be used to:

- Compute the execution time of each executive task (and, in turn, the spare time) for each of the eight minor frames.
- Provide data for a general analysis to be performed by recording the outputs of simulations run under identical flight conditions (cruise mode) but at varying iteration rates. These outputs will then be compared to the outputs of the baseline validation software run at 80-Hertz rate.

After the test was completed, a listing of all of the new FCL procedures were provided. The FCL timing variables affected by these procedures were highlighted on listings and given a unique identifying label. This unique label was included as an element in a matrix which was constructed according to Figure 2-8. In the left hand column, the procedures which were changed are listed. Broken out under each procedure are the variables of the procedure which now possess different values due to the modifictions. Across the top of the matrix are the various iteration rates that were used during the study. File comparisons of all modifications to existing procedures were provided. The reasons for these modifications were explained in the Iteration Rate Study Post-Test Requirements Technical Memo.

2.1.5.2.5 Verification of the Quad Channel Flight Control Software

The tests required for verification and functional testing of the quad channel flight control software were the same tests used in the single channel flight control software verification discussed in Section 2.1.5.2.3, but using only pitch attitude as the input.

Iteration Rate / Procedure Mods	80	60	40	X	X	X
I. Procedure 1						
a. Point 0	y					
b. Point 1						
c. Point 2						
II. Procedure 2						
a. Point 0						
b. Point 1						

Figure 2-8 FCL Software Modification Matrix

Where: Procedure 1 is the procedure in which three modifications occurred.

POINT 0 is the variable whose value is different from the baseline value due to the modifications. NOTE: The location of POINT 0 in the FCL program listings is highlighted and associated with this matrix by the unique identifier "Ia".

"y" is the computed value of POINT 0.

2.1.5.3 DSF Status and Utilization Status

STATUS

Direct Coupled Flight Control System Validation (SD80/PDP-11/40) (I) OCT 76.

Digital Hardware Voter/Monitor Design and Development (I) FEB 77

Digital Hardware Voter/Monitor/Hydraulic Actuator Integration and Evaluation (C) FEB 77

4-Port Memory Design and Development (I) JUL 77

Develop Cockpit System (C) OCT 76

Digital Aero Model Development and Test (PDP-11/34) (C-I) FEB 79

Design and Develop Flight Control Specification with JOVIAL Language (I) FEB 80

Single Remote Terminal/Flight Control/EOM (JOVIAL, 1553A Mux Bus)

Integration and Validation (I) FEB 81

Simplex Flight Control System Integration (1553A Mux Bus, JOVIAL) (I) MAY 82

Quad Redundant Flight Control System Integration (I) NOV 82

UTILIZATION

Technology Interchanges with Digital Synthesis

CE, Appliction of MIL-STD-1589B and MIL-STD-1750 to Flight Control

Lockheed (GA), Discussions on Using and Applying JOVIAL to

Flight Control

Boeing, McDonnel Douglas, Discussions on Use of MIL-STDs prior to

Release of RFP for C-X

SEAFAC, Continuous Discussions

FIGL, Digital Architecture

FIMS, Mission Adaptive WING ADP

FIF, Forward Swept WING ADP

FII, AFTI/F-16

RADC/AFATL, Input to Ada Program Support Program

Industry Assessment

2.1.5.4 DSF Support Requirements

The Digital Synthesis Facility required the following support throughout the ICSES contract:

- o Development of test plans and procedures
- o Modification of the FCL executive for iteration rate and the delta times of the computational procedures
- o Execution of the test procedures
- o Generation of technical memos
- o Analytical support including selection of representative samples and calculation of execution times, categorization of the FCL and identification of the advantageous/detrimental constructs of JOVIAL J73/I
- o Modification of the EOM software including the modifications to provide the capability to mask and rescale the interface data between 12-bits and less for each input signal individually
- o URT hardware support
- o Completion of the design in the new FCL executive impacted by DAIS protocol
- o Implementation of the new executive
- o Recoding of routines
- o Implementation of routines
- o Literature search.

2.1.6 Conclusions and Recommendations

Conclusions

The Digital Synthesis Flight Engineering Facility has provided a means to obtain hands on experience in application and use of control systems and applicable military standards including 1553 aircraft multiplex bus data standard, the 1750 minicomputer instruction set architecture standard, and the 1589 JOVIAL higher order language standard. The DSFEF provides a means to evaluate control system design

guides and measures assessment methods for control system perfc (i.e., ride quality, PIO tendencies, response crispness, etc.) MUX integrated control system.

The DSFEF software support task has provided a data/expe base on "effectiveness/efficiencies" of standardized systems for

- Computer efficiency/availability for a wide variety of computers
- Applicability to multi-variable controls
- Determination of critical design rules
- Programmer efficiency
- Validation and verification comparisons

Note that the experience and knowledge gained in use of the implies a strong need for facility capabilities to emulate designs in advance of freezing a design during the development cess. Early emulation of system designs will provide a me anticipate/avoid design flaws or "bad" designs. Also, expe gained in documentation and configuration control for changing s needed for DIGISYN may provide an experience base for AF life management control.

Recommendations

The use of the DSFEF has demonstrated the importance to h means to evaluate FCS capability. This capability should be cor and upgraded to a configuration with specific standards orient This would: give the AF a means to provide a credible influe evaluation of standards; provide a means for performing early s ic design hotbench testing; enable exploration of architectur information path options; provide provide a means to see the of control standards on fault tolerance, flying qualities, fu automations, etc., with pilot-in-the-loop emulation/simulations.

A second generation DIGISYN should be procurred and implem Specific requirements/critical capacities which should be addres

such a procurement include:

- Pilot-in-the-loop
- Safety
- Fault tolerance
- Freedom from idiosyncrasies
- Non-linear/coupled EOM
- Configuration control

A second-generation DIGISYN should also have the capability to address critical flight control technologies, as listed in Table 2.1-2. Consideration should be given to comparative efficiencies obtained through emulation of the target computer and also the use of/tie in with FIGD EOM support. Also, a formal configuration control approach for this type of facility must be addressed. However, specific configuration control requirements can be adopted so as not to impede development efficiency (see Section 2.4).

Table 2.1-2 Flight Control Technology Issues

- Specification of system level requirements
  - display/avionics/fire control integration
  - manual vs. automatic modes
- FCS test and evaluation
  - multiplicity of modes
  - S/W processes which are transparent to T&E
  - redundancy management effectiveness
- DFCS design
  - avionics integration
  - handling qualities specs. for non-classical modes
  - servo loop stability
  - system simulation
- Redundancy management
  - concepts and system architecture
  - sensor interface
  - distributed processing
  - testability
  - reliability assessment
- Control law design
  - design criteria
  - flight safety
  - handling qualities
  - re-design based on flight test
- Handling qualities
  - criteria
  - flight test techniques
  - control/display interface
  - task-tailored handling qualities

2.2 AFTI/F-16 PROGRAM

2.2.1 Program Background and Goals

In 1977 a study was conducted to determine the potential payoff to be derived by the application of the five technologies shown below to an F-16:

- Direct Force and Weapon Line Pointing
- Digital Flight Control System
- Integrated Flight and Fire Control
- Aerodynamic and Structural Design Improvements
- Pilot/Vehicle Interface Advancements

Before the trade study had been performed, the technologies were assessed relative to application on a new prototype aircraft. The trade studies were partitioned into two subsets.

The first subset was a configuration study in which aerodynamic and structural design advancements were coupled with a set of configuration options to generate varying levels of advanced flight mode authority. Incorporated at that time in the configurations were the aerodynamic and structural design improvements available from the technology base in the form of an improved wing and attendant fuselage changes required to balance the airplane. The baseline configuration, which can only generate decoupled motion in the pitch axis, was used to reference the performance impacts of adding yaw decoupling. A total of 769 hours of wind tunnel tests were conducted in the process of aerodynamic configuration development. A point design was evaluated for each configuration, and advanced mode authority plus conventional performance were computed. A definite trend was established with respect to increasing conventional performance penalty generated as advanced mode authority was increased.

The second trade study subset involved determination of the payoff derived by coupling advanced mode control authority with integrated flight and fire control.

Small amplitude fuselage pointing, generated either with a trainable fuselage or a trainable gun, rapidly saturated the gunnery objectives at an authority much smaller than could be gained with the minimum conventional performance impact configuration. Also, very large advantages were identified for cases in which flight control and fire control were integrated.

The benefit/penalty assessment coupled with a reduction in program funding resulted in the elimination of the aerodynamic and structural design improvement technology from the planned program. On 22 December 1978, General Dynamics was selected to develop the AFTI Technology Set I and the AFTI/F-16 Testbed Aircraft.

Program rationale was clearly stated in the contract work statement. Highlights of the rationale include:

1. Provision of a demonstrator aircraft for demonstration and validation of the integrated technologies in a configuration that permits functional assessment in the tactical environment.
2. Development and integration of the individual technologies in a manner which minimizes the need for testbed aircraft.
3. Provision of a consistent and compatible goal that encourages integration across the large number of functional disciplines involved.
4. Establishment of design criteria as the salient objective of the individual projects in addition to the total program.

The testbed aircraft, called a technology demonstrator, (Figure 2.2-1) is in fact a system prototype. The emphasis in technology is consistent with emerging fast-track technology, microelectronic-based systems, and Air Force needs, which are improved navigation, engagement and weapon delivery capability -- or weapon line control.

2.2.2 <u>Program Description</u>

The AFTI/F-16 Advanced Development Program is a joint USAF, Navy,

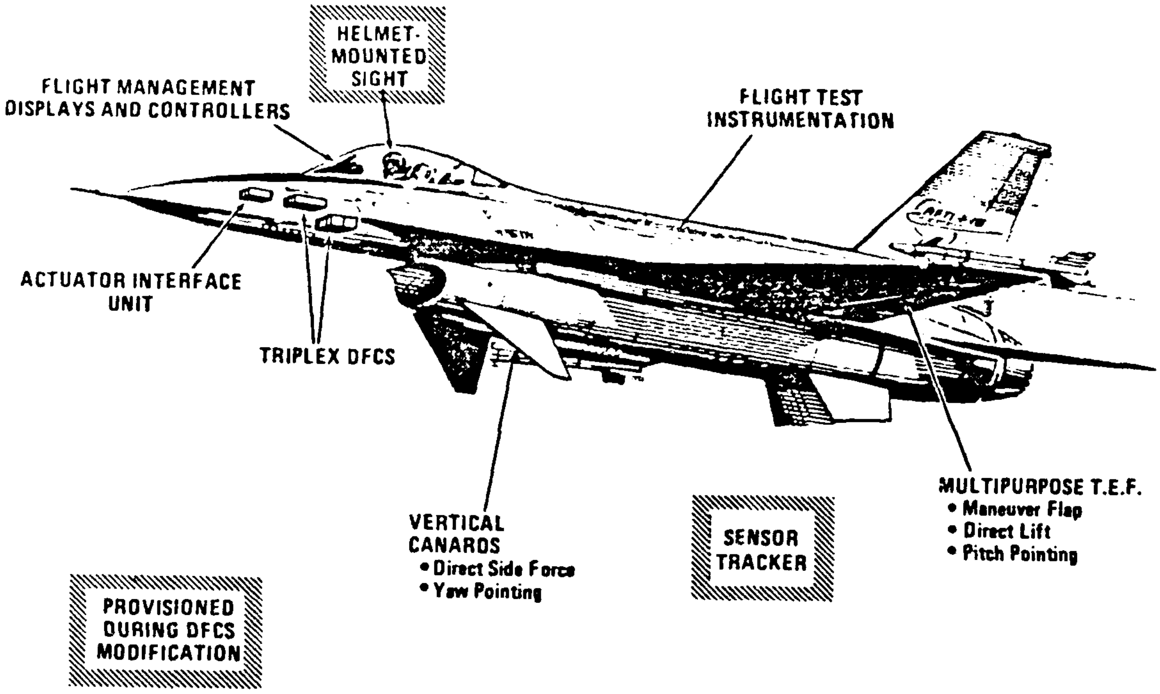


Figure 2.2-1 AFTI/F-16 Technology Demonstrator

and NASA effort aimed at the development, integration, and flight test evaluation of emerging technologies for improving fighter aircraft mission effectiveness. Major development thrusts include Digital Flight Control System, Direct Force and Weapon Line Control, Pilot Vehicle Interface and Automatic Maneuvering Attack System (AMAS). Development of an advanced highly reliable digital flight control system (DFCS) is the core technology building block for accomplishing the overall AFTI/F-16 objectives.

Application of digital flight control technology offers the opportunity to integrate these advanced concepts in a multi-role, high-performance fighter aircraft to achieve operational versatility, improved overall mission effectiveness and decreased cost of ownership without sacrificing system reliability and safety. The DFCS portion of the program encompasses the complete development and integration of a multimode triplex digital FBW flight control system employing decoupled six DOF flight path control capabilities. Major technical thrusts include the development of: (a) task-tailored mutimode control laws incorporating direct force and weapon line pointing features, (b) triply redundant flight control computer complex using the BDX-930 processor, (c) advanced redundancy management techniques, which provide essentially two fail-operate capability and meets or exceeds a loss of control reliability of 1 x 10-7 failures/flight hour, (d) integrated crew station using multipurpose controls and displays, and (e) compatible interface for integration with other subsystems, such as fire control, mission avionics and associated multipurpose displays, through a common digital data bus.

Organizing primary flight control modes and associated control laws based on specific mission/weapon delivery requirements offers the opportunity for enhancing overall mission effectiveness, while at the same time emphasizing the pilot's role as a mission manager rather than a subsystem operator. In consonance with this design philosphy, the following basic mission tailored control modes are implemented in the AFTI/F-16 testbed; (a) Normal Mode with ancillary functions for take-off/landing, refueling, formation, cruise and pilot relief; (b) Air-to-Air Gunnery Mode, (c) Air-to-Ground Mode, and (d) Air-to-Ground

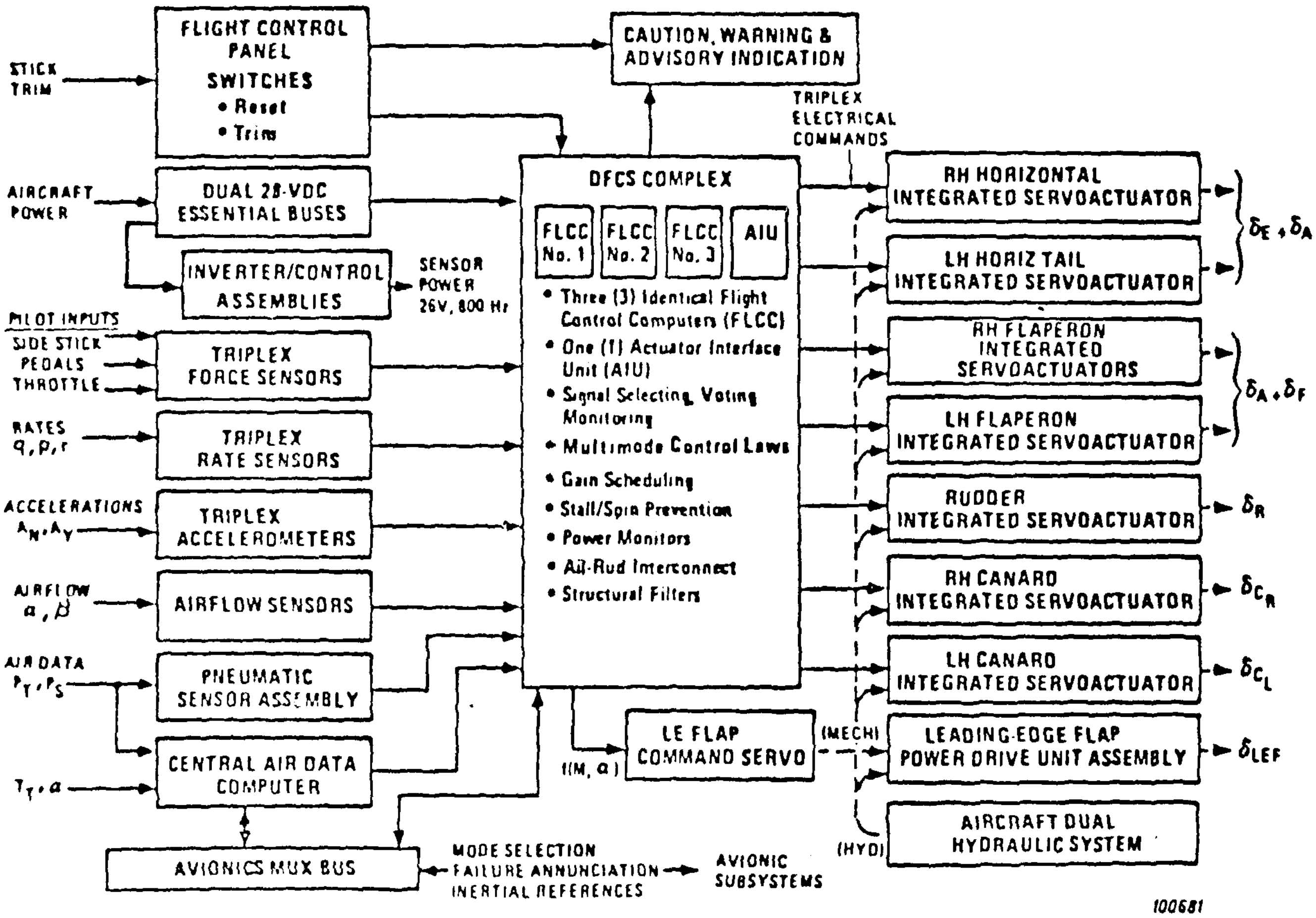


Figure 2.2-2 Triplex Digital Flight Control System

Bombing Mode. Control law/sensor reconfiguration schemes are also employed to provide optimum flight characteristics based on available functioning system elements. In each of these primary modes, the flight control system provides the necessary flight path decoupling, and desired vehicle response characteristics, specifically tailored and optimized for the appropriate mission segment. Digital technology is especialy suited for implementing these sophisticated inner loop control functions and interfacing with other avionic subsystems such as the fire control system.

During Phase I of the program, the digital flight control system (DFCS) was designed, constructed, and successfully flight tested. In addition to the flight control system, other emerging technologies have been investigated during this phase. Among these are: a wide-field-of-view HUD, multi-purpose display unit, and a voice interaction system. The significance of the AFTI program relative to future fighter aircraft, however, lies in the accomplishments anticipated for Phase II. In this Phase of the program, denoted by the acronym AMAS (for automated maneuvering attack system-Figure 2.2-3), the digital flight control system will be integrated with other avionics subsystems - the stores management system, and the fire control system. Through this judicious coupling of flight systems, the advantages of task-tailored control laws and decoupled motion made possible by the DFCS and advanced aerodynamic structure are brought directly to bear on the problem of weapon delivery. When the pilot and his crew station are also properly integrated, the result will be significantly enhanced fighter mission effectiveness.

Among the new technologies to be evaluated during the AMAS phase are:

- YAG Laser/FLIR
- Helment-mounted sight
- Roll-stabilized radar altimeter
- Digital map and display
- Standardized avionics integrated fuzing (SAIF)

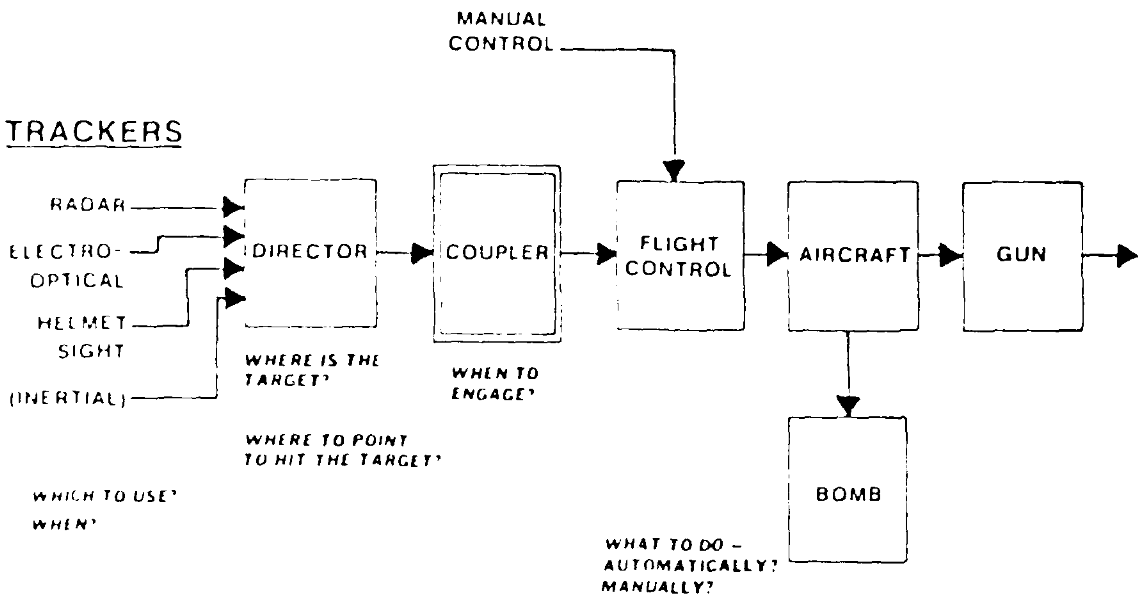


Figure 2.2-3 Automated Maneuvering Attack System

2.2.3 Program Status and Plans

The AFTI/F-16 demonstration aircraft is currently under modification at General Dynamics' Ft. Worth facility in preparation for the AMAS phase of the program.

The concept for the AMAS phase is to add an electro-optical tracker to the testbed aircraft and to host the integrated flight/fire control FFC) system software in the testbed aircraft. The principal objectives of this phase are:

- Integration of digital multimode flight-control system, advanced fire-control system, advanced controls and displays, and weapons for validation of IFFC system performance and mission effectiveness.
- Identification, design, and implementation of IFFC configurations and quantification of improvements in weapon delivery capability, accuracy, and survivability.
- Determination of pilot acceptance, adaptability, and workload reduction associated with the IFFC modes in the weapon delivery phase.

Several design features have been specifically developed for demonstration of the low-altitude attack capability:

- System Wide Integrity Management (SWIM)
- Automatic Ground Avoidance
- Automatic Ingress and Egress Steering
- Low Altitude Radar Auto Pilot
- Conformal Sensor/Tracker Installation

The AMAS system has been updated with available F-16 Multinational Staged-Improvement Program (MSIP) hardware. The benefits of this change are to provide all AMAS avionic software in standard J73 source code and to improve testbed aircraft supportability.

At the present time, the AFTI/F-16 program is expected to be completed by mid-1985. There is, therefore, no formal definition for Phase III activities. However it is reasonable, and quite possible, to expect the basic AMAS system demonstrated during Phase II to be

expanded to include terrain-following/terrain-avoidance and night-attack capability.

2.2.4 Work Accomplished

2.2.4.1 Documentation and Design Review Support

Over the course of the program SCT reviewed and evaluated software documentation produced by General Dynamics. This documentation included:

- Computer Program Development and Product Specifications for the Operational Flight Programs resident in the flight control computers, the fire control computers, and the Stores Management Set.
- Computer Program Development Plan
- Flight Control System Software Mechanization Document
- System Test Plan
- Software Verification/Validatin Plans and Procedures for stand-alone, and integrated system testing of the Operational Flight Programs.
- Software Verification/Validation Test Reports
- Deficiency Reports
- Software Mechanization Change Requests
- Display Control Documentation
- Design Review Minutes

All documentation was evaluated with a view to discovering errors, inconsistencies, omissions, or other significant departures from accepted industry standards and known system operating characteristics. Detailed comments and suggestions were provided to the Program Office and all review activities were documented in the weekly activity reports as well as the monthly progress and status reports.

SCT also provided continuous design review support throughout the program. This support included participation in all system design reviews, safety reviews, and numerous technical coordination meetings,

including the Flight Readiness Review, which were conducted at General Dynamics/Ft. Worth as well as at the Program Office at Wright-Patterson AFB, Ohio.

2.2.4.2 Software Design Review and Analysis

The purpose of SCT's software design review and analysis task was to provide a comprehensive independent assessment of the software design. The software design was reviewed for adequacy and completeness, as well as compatability and compliance with requirements specifications. Two methods were employed to validate the basic integrity of the OFP software. First, a detailed knowledge of the software was obtained through a continuous process of documentation review, participation in technical coordination meetings, pencil and paper analysis of logic flow and control laws, and first-hand observation during the V&V testing effort. Second, both an emulation and a batch simulation were constructed to examine specific problems and system characteristics. The batch simulation will be discussed in Section 2.2.4.4 - On Site Support.

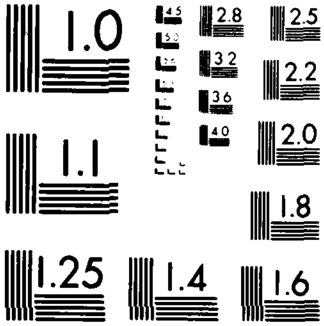
Overall evaluation and specific recommendations concerning the software design were provided in the form of documentation reviews, commentaries on the minutes of system design reviews, and basic "position" papers formulated and issued as required throughout the program. In particular, SCT provided analyses and recommendations to the program office on the following issues:

- DFCS control law logic design
- DFCS control law intermediate data analysis
- Handling of dual failures by the Failure Management System
- Random flight control computer trip-outs
- Flight control computer burn-in requirements
- Low level V&V testing of fully integrated OFPs
- Sequential data link receiver failures
- Software testing issues
- Output selector/monitor robustness
- Control law reconfiguration

Prior to First Flight, SCT organized an extensive test coverage audit of the flight control software. The purpose of this software audit was to verify that the computer program test coverage is adequate to safety of flight for the flight test program. The verification activity consisted of reviewing software test procedures and correlating them with the requirements set forth in the DFLS mechanization document to assure that completed and planned tests support safety of flight. The scope of the audit covered the computer programs resident in the AFTI Flight Control Computers (FLCC). The critical software segments were the flight control laws and the failure management implementation. Remaining segments were reviewed on a sample basis. The auditors assured that a professional and prudent verification activity was accomplished by General Dynamics. Subsequent to the V&V testing activity a software test results audit was performed to verify that actual test results were in agreement with expected test results.

As noted above, in addition to a comprehensive software review and various "pencil and paper" analyses SCT also constructed an emulator to examine specific flight control system characteristics. The AFTI/F-16 Emulator, written in Pascal and hosted on a Vax 11/780 at SCT's Palo Alto facility, became fully operational early in 1981. It contains the software written by General Dynamics, models of various sensors, the ISA interface and a longitudinal axis model of the F-16. It is driven by a discrete event simulation executive which simulates three FLCC's running asynchronously. The software residing in the FLCC is a high order representation of the General Dynamics software. It accurately reflects the General Dynamics design in the areas of ISA and input selector monitors, Failure Management, IOC processing and hardware (particularly ISA hardware). The controls law have been simplified and only Longitudinal normal and decoupled modes are implemented. The emulator was utilized to explore a varitey of flight control system characteristics and problems; these are summarized below:

AD-A149 742 INTEGRATTD CONTROL SYSTEM ENGINEERING SUPPORT(U) 2/3
SYSTEMS CONTROL TECHNOLOGY INC DAYTON OH
W H CLARK ET AL. DEC 84 AFWAL-TR-84-3068
UNCLASSIFIED F33615-79-C-3614 F/G 1/3 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

- Redundancy Management Analysis
  - selector/monitor design
  - reset logic
  - watch-dog timer disable logic
  - high level device failures
  - mode transition
  - failure modes and effects
  - persistence
  - trip levels
  - interchannel tracking
- Control Law Studies
  - frequency response, nominal and failure
  - mode transition/reconfiguration
  - control law intermediate data analysis
  - step response
- FCS Software Integration
  - test matrix correlation
  - software change request validation
- System V/V Testing
  - refine test procedures
  - DR/MCR/SCR validation
  - test results correlation
- IFFC
  - architecture studies
- General
  - resolution of discrepancies between the mechanization document and the product specification.

2.2.4.3 Lateral Investigations

In addition to providing an independent assessment of the software design, SCT was also tasked to provide analysis in support of design trade-off studies, and to permit the program office to properly evaluate potential changes to the program. The most significant of these activities were the IBU modeling effort and the preliminary per-

formance assessment study.

IBU modeling effort - The independent back-up unit is a simple, but vitally important, analog controller designed to ensure safe flight in the event of digital system failure. Performance requirements of the IBU are to meet Level 3 requirements of MIL-F-8785 (ASG) for cruise and descent and Level 2 for landing. Control in the longitudinal axis is provided by a pitch-rate command system. The pitch command from the stick is shaped and then lagged by a prefilter. The pitch rate error signal is then gained and fed through a proportional-plus-integral network. Different lead/lag compensators for the gear-up and gear-down configurations augment stability margins and improve handling qualities over the entire flight envelope. SCT constructed a computer simulation of the IBU by transforming the continuous-time transfer functions into difference equations. This simulation was then used to provide confirmation of the IBU's stability and frequency response characteristics.

Performance Assessment - The AFTI/F-16 is a technology demonstration for future fighter aircraft. As such it's primary role is that of being a testbed to explore new technologies for their potential in enhancing fighter aircraft performance and mission effectiveness. It is reasonable to expect that the new technologies incorporated into the AFTI/F-16, when taken together, will result in significant improvements in target acquisition time, tracking accuracy, probability of hit, and survivability. However, there needs to be precise quantification of this improvement as well as the correlation between specific technology and enhanced performance. SCT prepared a detailed plan delineating methods for conducting comprehensive and meaningful performance assessment studies.

2.2.4.4 On-Site Support

SCT provided on-site support to the AFTI/F-16 Joint Test Force (JTF) at Edwards AFB. These services were provided starting with the digital flight control system (DFCS) development phase at General Dynamics Fort Worth and continuing through actual flight test. SCT

supported this program in 5 distinct areas:

- Development of six-degree-of-freedom batch simulation of the AFTI/F-16.
- Systems engineering support to the analysis, development effort, and flight test of the DFCS phase.
- Support of flying qualities test and evaluation of DFCS.
- Systems engineering support of development efforts required for the AMAS phase.
- Documentation control and clerical support to the JTF.

On-site support at Edwards AFB was accomplished under technical direction of NASA DFRF, as part of an MOM between NASA DFRF and AFWAL. Operational management of this support was accomplished in matrix fashion: SCT-to-DFRF-to-JTF.

On-site support services, under the ICSES contract, ended on 30 September 1983.

Batch Simulation

A full 6-DOF batch simulation of the AFTI/F-16 was developed at the request of NASA DFRF. The simulation was validated over a limited range of flight conditions for the IBU control laws, only. This effort proved to be much more difficult and costly than originally conceived. This was due mainly to the enormous size and complexity of the aerodynamic data base and the attendant problems of validating the aero data package after its installation on the Cyber computer facility at NASA DFRF.

The batch simulation effort has been documented in an informal report. The simulation is presently hosted on the NASA DFRF Cyber.

DFCS Support

During the DFCS phase of AFTI/F-16, SCT supported 114 flights at Edwards AFB over a 12-month period. Prior to first flight, SCT personnel were instrumental in developing the technical basis and

operational ground rules required for support of the triply-redundant, dual-fail Op DFCS. This included participation in establishment of the software review and control process - which was instrumental in the conduct of an orderly, safe flight test program. The support provided to DFCS development and testing was in four principal areas: software systems, flight test and technical reporting.

Software support included a spectrum of activities ranging from development of top-level understanding of DFCS functions to dealing with the volume of paperwork generated by the software control process. SCT was an active participant in establishing the Software Control Board (SCB). A major work area was the development or review of confidence tests at GDFW, and software verification and validation testing. SCT also generally prepared the NASA OFP Release Document for each DFCS OFP modification after the airplane entered flight tests at Edwards AFB. There were a total of 13 OFPs.

In the area of systems support, SCT participated in various systems-related tasks, involving both hardware and software, and which usually involved cross-disciplinary functions. These support duties included participation in the Configuration Control Board (CCB), Flight Readiness Reviews (FRR), and review of Discrepancy Reports (DR), Change Requests (CR) or Mechanization Change Requests (MCR). A periodic function was to prepare, and often give, a formal NASA Tech Brief prior to each flight test block, first flight following a new OFP installation, or after a major system anomaly was experienced in flight test. Substantial real-time simulation was conducted on the AFFTC simulation of AFTI/F-16 to evaluate various features of DFCS software redundancy management vs. control laws vs. system dynamics. This included evaluations of trip level requirements for asynchronous DFCS operation. Control law modifications were routinely evaluated prior to approval of MCRs for OFP modification. The unique test requirements for voice command received considerable support. A regular schedule of travel to GDFW was established to provide support of system test and evaluation on the GD simulator.

Once testing was begun at Edwards AFB, the direct and indirect support of flight schedules became the priority work item. Flight

support actually started well before the airplane was delivered to the Joint Test Force (JTF). Substantial effort was required to define instrumentation requirements, control room layout, go/no-go parameter lists, and specific operational test support procedures. A control room manual was prepared by SCT for DFCS support. Combined systems tests were conducted following major change to system hardware (including the airplane, control room, and instrumenataion). A combined system test was made of the control room prior to the airplane's arrival at Edwards by using a TM tape from the first flight at GDFW. Routine support included review of Block Test Plans, participation in crew briefings, flight monitoring, and crew debriefs. Any DFCS anomaly experienced in flight became the subject for rigorous, priority investigation to determine probable cause and, if required, present the results at a formal NASA Tech Brief. Substantial support was given to the Hi-alpha test plan. This included test plan review, simulations at GDFW and the AFFTC, and support of NASA Tech Briefs.

In the area of technical reporting, two papers were jointly authored by SCT with NASA on the DFCS:

(1) Mackall, Ishmael & Regenie, "Qualification of the Flight Critical AFTI/F-16 Digital Flight Control System", AIAA-83-0060, AIAA 21st Aerospace Science Meeting, Jan. 10-13, 1983

(2) Ishmael, Mackall & Regenie, "Ramifications of the System Design of the AFTI/F-16 Digital Flight Control System", 5th Digital Avionics Systems Conference, Oct. 31 - Nov. 3, 1983, Seattle, Wash.

Flying Qualities

SCT was a very active participant in flying qualities T&E during DFCS. This support was of two types: operational support of the JTF misison requirements and general technology support.

Operational support covered a variety of activities including:

- direct flight test support (crew briefings and debriefings, and control room monitoring of flights),

- test planning (supplementing the Test Plan Document with specific, day-to-day details which enhanced the quality of testing results or test technique),
- active participation in the configuration control process,
- review of propsed DFCS control law changes,
- flying quality discrepancy investigations.

One of the objectives of the AFTI/F-16 program is to contribute to an expanded technology data base. SCT was instumental in fulfilling this responsibility during the DFCS flight test phase. This was done by searching for, or creating, test opportunites throughout flight test. These, when fully exploited and reported, contributed to flight control technology with aircraft systems and missions such as those encompassed by the AFTI program. Usually, but not always, these technology opportunities resulted from a flying qualities discrepancy. Thus, the SCT support to flight operations and technology were integrated processes.

There were 10 principal areas where SCT provided flying qualities expertise to the DFCS flight test program, as follows:

1. Roll pilot-induced-oscillation (PIO): Three PIO experiences were encountered, all in the roll axis. The first occurred in the standard normal control mode during power approach. The task was an offset approach, touch & go, in a gusting crosswind. The second was at 1.2M in IBU. The third was in the simulated USN carrier approaches. These PIO events were analyzed by SCT.
2. U.S. Navy carrier approach "simulations": These were actual power approaches, using a Fresnel Lens Optical Landing System (FLOLS), and a ship's-qualified Landing Signal Officer (LSO). All aproaches were terminated with standard Shipboard wave-off techniques, commanded by the LSO. An F-16A was tested first to develop the test technique and to provide an AFTI baseline. Roll

PIO was encountered with AFTI; it was identical with that obtained in the cross-wind landing. SCT personnel, experienced in carrier air operations, supported both these tests by assisting the LSO, preparing custom pilot evaluation scales, and arranging Askania coverage for the AFTI test.

3. Pilot evaluation scales: the AFFTC flight test team was experienced with the standard methods for obtaining pilot ratings and comment data. However, in view of the practical limitations of the AFTI/F-16 test coverage, there was genuine concern that these would be inadequate. To supplement the evaluation process, SCT devised AFTI-unique evaluation forms. These were used routinely for most flights of flying qualities interest.
4. Roll ratcheting: This problem, previously encountered with the AFTI/F-16 aircraft was encountered very early, and an attempt was made to cure the problem with roll command prefilters. SCT performed substantial analyses of system dynamics (airframe-control laws-pilot); these successfully explained the cause of the ratcheting and suggested a cure. A major conclusion was that, for AFTI, command prefilters were an unlikely source for a ratchet cure - - although ratcheting could be eliminated at the expense of degraded tracking. This was verified by case history data from 3 successive DFCS OFPs.
5. Handling qualities during tracking (HQDT): SCT proposed the use of HQDT for testing AFTI flying qualities in the PA configuration. This was actually done, using an F-16 as the target aircraft (to match AFTI's approach speed). Although the requirement to avoid jetwash was a real problem (it required extreme depression of the fixed reticle sight), the method successfully demonstrated all the features of AFTI PA flying qualities that were found with more difficulty through conventional testing. This included the roll PIØ mode. HQDT testing

indicated a pitch axis control problem that was never seen in actual PA -- although some pilot comments did support the HQDT results.

6. Pitch sensitivity in aerial refueling: throughout DFCS, the airplane demonstrated a significant sensitivity in the pitch axis when connected, or even near the tanker. SCT proposed and evaluated various control law modifications which were implemented by GD to eliminate the problem.

7. LCOS dynamics: SCT devised the plan used by the JTF for tracking evaluations of AFTI dynamics. This was the jinking target superimposed on standard HQDT practice. The data generated by this testing was used by SCT to obtain an identification of LCOS dynamics. This was done using the frequency response analysis (FRA) program at the AFFTC. The resulting identification of LCOS dynamics was of very high quality. This, to our knowledge, was the first time that fire control algorithm dynamics were identified from flight test data.

8. Identification of AFTI dynamics: SCT played a principal role in stimulating the analysis of AFTI tracking data within the JTF to determine frequency response models for AFTI dynamics. SCT also reviewed all these data for the purpose of quantifying varions flying qualities behavior.

9. Trim as a flying qualities parameter: SCT proposed the use of trim variations as a tool for identifying, stimulating, or quantifying flying qualities deficiencies. This technique was successfully used on one flight for characterization of the pitch sensitivity problem during refueling.

10. In connection with analysis of the beta departure (Flight 36), it was determined through the use of the AFFTC simulation of AFTI that aircraft dynamics could be easily obtained (frequency response form) at near-departure conditions. The technique used was to generate doublet

responses and analyze these with FRA. The results were of very high quality. This has been proposed as standard flight test practice for high alpha/beta flight conditions.

AMAS Support

Work was performed in two distinctly different areas. The primary effort was for ad hoc support of PDR and CDR activities. This included reviewing AMAS requirements, documentation, pre-CDR test plan, and attending the PDR and CDR. With the completion of the DFCS phase of the flight test program major efforts shifted to support of the AMAS system development and preparations for test support at EAFB. The objective of these efforts, which are continuing, is to support the overall technical program of the AFTI/F-16 Joint Test Force to develop and maintain the technical competence required for the AMAS flight test program requirements. The SCT work specifically addresses the systems level interactions between the avionics systems and the DFCS. This includes development of detailed understanding of all system software, hardware, ICDs, product specifications, and integrated system testing plans and implementation at GDFW. A major portion of this support effort has been dedicated to the development of strategies for safe and efficient monitoring of AMAS flights and the attendant problem of providing post-flight analysis support. Because of the avionics-intensive nature of the AMAS system, it is believed that more accessibility to the telemetry data stream will be required to provide the technical support required by a modern flight test effort of AMAS complexity.

The secondary effort was initiated very late in the program following the close-out of batch simulation activities. The latter effort was begun at NASA DFRF request and has continued into FY84 under separate NASA funding. Its objective is to develop a preliminary approach to the methodical design of fully integrated, redundant digital flight control systems, and to use the result as a tool for the analysis and support of AMAS development and flight test. Work is

continuing in preparation for AMAS flight testing. The developmental effort which supports a NASA technology objective has matured to a prototype form, useful for the refined resolution of requirements for a fault-tolerant, distributed processor, integrated control system. Work will continue on this during early FY84, after which an attempt will be made to apply lessons learned to analysis of the AMAS system.

Documentation Support

SCT's on-site support at Edwards AFB and NASA DFRF including maintaining the mass of program documentation required for operation of a flight test program. This effort included establishing and maintaining the documentation library of approximately 700 reports, with accession lists and computer data base; it also included the distribution of key technical reports to cognizant disciplinary engineers and program management. Although this support area was entirely clerical, it was absolutely vital to the smooth functioning of the Joint Test Force. Throughout the DFCS flight test program, no time was ever lost because the staff lacked proper system documentation.

2.2.5 Conclusions and Recommendations

Over the duration of this contract SCT provided support to the AFTI/F-16 Program Office with the following activities:

- documentation review
- design review report
- software design review and analysis
- digital flight control system verification and analysis
- independent studies and design trade-offs
- on-site support including simulation development, control system analysis, flight test support, and handling qualities analysis.

All of these support efforts were thoroughly documented in weekly

activity reports, monthly progress reports, and technical memos issued as necessary.

As noted previously in this report, the AFTI F/16 program is currently in the AMAS development phase. The overall complexity of the system will be even greater than during the DFCS phase. This additional complexity arises because several new techniques are to be integrated and evaluated simultaneously. Therefore, SCT believes that the need for independent support is more acute now than during Phase I. In particular, SCT recommends that continued support be sought in the following areas:

- documentation review
  - mechanization document
  - test plans and procedures
- software design assessment
- design review participation
- software test procedure and results auditing
- independent studies
  - system wide integrity management (SWIM) implementation
  - AMAS performance assessment
- on-site support
  - AMAS simulation
  - handling qualities evaluation

2.3 TRANSPORT ADVANCED CONTROL SYNTHESIS (TRACS)

2.3.1 Program Background and Goals

The emphasis of the TRACS program is to demonstrate advanced control synthesis applications for transport aircraft and to evaluate the feasibility of crew station integration concepts. The TRACS program is comprised of four main activities, namely, (1) flight trajectory investigation, (2) throttle/energy management, (3) transport advanced control technology and (4) tanker integration and evaluation. A representation of the relationship of these areas and various programs within each of them is shown in Figure 2.3-1. The flight test bed to demonstrate the post-1980 military transport mission is the Speckled Trout (C135-C) aircraft which is equipped with a digital flight control system (Sperry), advanced displays, and a number of inertial/area navigation (Collins) systems. Flight control performance improvements have been demonstrated by incorporation of digital systems. Analysis and applications of integrated throttle/flight path control techniques enable a pilot or automatic control system to regulate an aircraft's potential and kinetic energy. The TRACS program has utilized a systematic design approach to systems integration investigations of controls/displays/sensors/pilot to provide the potential for increasing operational mission performance.

2.3.2 Work Accomplished

The tasks performed fall into four areas: Software Acceptance Review, Flight Control Law Analysis, Simulation/Validation Facility Development Support, and Flight Control Test Support.

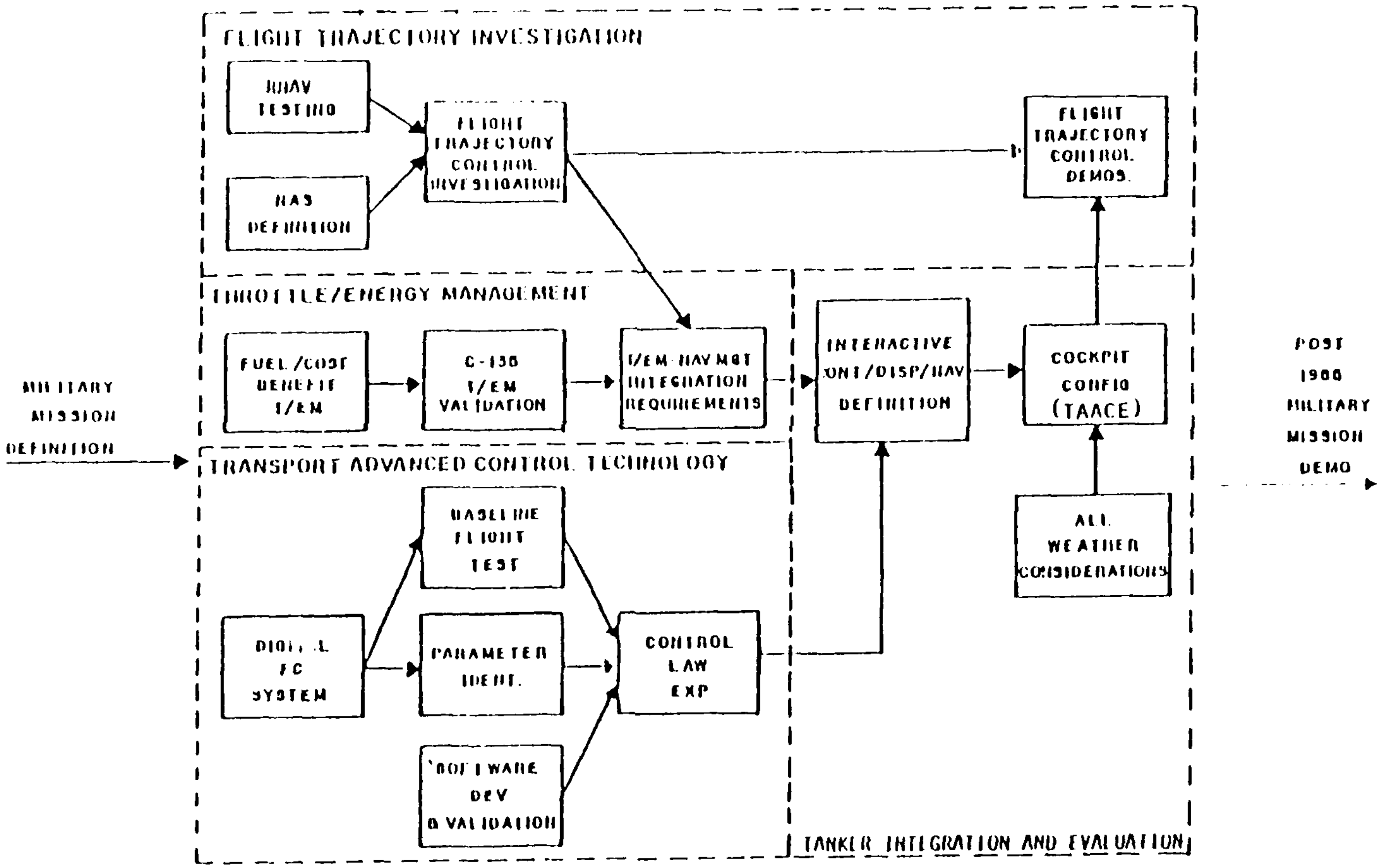


Figure 2.3-1 Transport Advanced Control Synthesis (TRACS) Program

2.3.2.1 Digital Flight Guidance System (DFGS) Software Acceptance Review

SCT provided support to FIGL in receiving, reviewing and documenting the Sperry 1819B computer and associated software. The activity included providing documentation of the system and generation of recommendations of additional features to enhance system capabilities. The effort required review of the avionics software provided and associated support software used for software modification, simulation and flight analysis. As a result of the software review, a number of system enhancements were identified/recommended.

Central to the following discussion of system enhancements to improve development and validation efficiency, more memory capability is required in the DFGS system. The basic system utilizes 16K core memory and is operated in the Speckled Trout in that configuration. The system currently supports only minimal digital data recording capability and requires significant software modification and auxiliary memory to support ground-based simulation. The basic avionics system should include 32K core memory. The additional memory would allow for basic system enhancements, simulation and research interfaces, enhanced utility capability and implementation of alternate research algorithms. The software should be modified to provide skip key control of the simulation and research options similar to systems developed by Sperry for the Stoland and V/Stoland for Ames Research Center.

RECOMMENDATIONS/CONCLUSIONS - During software development and checkout, it is recommended that each change to the system be accompanied with software engineering documentation. The documentation should include the reason for the software change and the implementation method used to incorporate the change. If a new assembly was performed, the listing and variable cross reference table should be provided. In any event, some form of mnemonic listing should be provided. Associated with each software change, a detailed flight plan (or simulator study) should be generated to validate each revision incorporated.

- Digital Data Recording - It is recommended that the number of

variables recorded be increased to at least 80 by either increasing the size of the data buffer transferred or by multiplexing methods. Engage mode status words, packed discretes and monitoring-valid words should be recorded. A recommended enhanced data list where the time tagging of the data is assumed to be appended during PCM recording was provided to the Air Force.

- Keyboard Gains - A table of keyboard gains was presented which should be adjustable inflight to 50-200% nominal value.

- Aircraft Simulation Facility - It is recommended that a ground based simulator be developed to allow adequate analysis and resolution of current system anomalies. A simulator could be used for testing alternative control system gain strategies or duplicating anomalies found in flight testing in a controlled environment.

2.3.2.2 DFGS Flight Control Law Analysis

This task examined the performance of the Digital Flight Guidance System (DFGS) software. Testing and analysis of the DFGS software was performed so as to assist FIGL in analyzing DFGS software performance. This software testing was augmented by reviewing documentation of previously performed stability analysis and by performing additional linear analysis.

Lateral Control System Analysis

Preliminary identification of anomalies in the KC135 Speckled Trout Digital Flight Guidance System has resulted in a detailed description of the lateral control system to permit a more informed selection of control system gains. The full report was given to the Air Force. The KC135 aircraft itself, without any stability augmentation, is inherently lightly damped in its dutch-roll response. During program development, system validation, using a ground-based simulator

was performed. The aircraft model used in the validation was approximate and a more accurate model is now available. In addition, during the development of the control systems and preliminary flight testing, considerable program modification has been performed. Since simulation facilities are not available, a linear analysis approach was utilized to assist in the evaluation of the existing lateral system.

RECOMMENDATIONS/CONCLUSIONS

- Adjust KYAWRT according to root locus analysis and evaluate performance.
- The feed-forward component of the rudder control system, not presently used, could be modified to provide an aileron displacement component. The adjustable feed forward gain, KYAWFF, could be used to incrementally incorporate the effect in the control system during evaluation.
- Establish a specific data list to diagnose the rudder and aileron control systems. Major components of the control commands should be recorded along with mode control flaps. Recommended variables include: ZTWO2, YAWRRF, YAWRCF, and YDENGF.

DFGS Autothrottle Analysis

Pilots of the Speckled Trout aircraft expressed dissatisfaction with the autothrottle's performance at low altitudes and Mach numbers of 0.3 and less. Therefore, a representative flight condition was chosen as the basis for this study, the coupled airframe-engine-pitch control-autothrottle system was simulated, and changes in the values of autothrottle gains and minor changes in the autothrottle design were investigated for improved performance.

The autothrottle and its environment, i.e., its interaction with the longitudinal aerodynamics of the airframe, the engine thrust

acceleration and deceleration dynamics, the pitch control loop, and the control servomechanisms were analyzed.

Initially it was hoped that a linear analysis of the system would be possible, for then tools such as root-loci plots and eigensystem analysis could be applied. However, it was soon evident that some components of the coupled system could not be represented adequately by linear differential equations. This is particularly true of the engine thrust acceleration dynamics and the digital logic of the autothrottle and pitch control. Hence, it was necessary to resort to developing a simulation of the system and to study the time-history response directly. This approach was further necessitated because a Speckled Trout simulator with the DFGS software operating in an 1819B computer was not available.

The nature of this study is necessarily qualitative since, first, flight data on autothrottle variables in the form of strip charts, for example, was not available, and second, what constitutes good autothrottle performance is partly a subjective judgement.

RECOMMENDATIONS/CONCLUSIONS

Of the six autothrottle gains which were varied to study their influence on performance at a specific flight condition, two showed promise for improving the response. Of these two, the better improvement was shown by decreasing the time constant of the lag element whose output leads to the throttle command THRCMD. In the DFGS software, this means increasing the value of the eleventh element of the array ZFGEAA, whose present value is 0.00631 corresponding to a time constant of 8 seconds. For a desired time constant of τ, this value should be changed to

$$1 - e^{-.05/\tau}$$

Lesser improvement to the autothrottle response results if the gain KT1P8 is increased (i.e., made more negative). Its present value is -1.8. One side effect of such a change was to shorten the period of the outer-loop autothrottle oscillations, which is judged undesir-

able.

The minor software change of including a gain greater than one on the velocity rate input also produced improved response. However, if the velocity rate is noisy, performance would be degraded through the amplification of this noise. It is recommended that the changes described above be tried in the order presented.

2.3.2.3 Simulation/Validation Facility Development Support

The objectives of this task were three-fold:

- Take the initial steps for facility layout and integration with other equipment in the Digital Synthesis Flight Engineering Facility (FEF), Bldg. 145.
- Explore the use of an AN/AYK-15 and 1553 data bus to implement the Flight Control Research Computer (FCRC) and communication function with the Sperry DFGS.
- Implement the previously developed Speckled Trout aerodynamic model (with simplified throttle and engine models) on the FEF PDP-11 computers.

In the absence of a Sperry 1919B computer, facility lay-out and integration had to be performed in a preliminary way. This was accomplished using an AN/AYK-15 computer to "model" the Sperry computer.

A second AN/AYK-15 was used to represent the FCRC. A Universal Remote Terminal (URT) interfaced the 1553A bus with a PDP-11/34, where the aircraft equations of motion resided. Sensor data and actuator commands constituted the information flowing in and out of the EOM over a 1553A bus.

To demonstrate that this configuration was workable, SCT first loaded the Sperry 1819B model with guidance and control software and repeated a selected guidance algorithm in a second processor, the FCRC. SCT then implemented software to effect the following sequence:

1. Sperry 1819B model feeds Guidance input data to FCRC model.
2. FCRC model computer its Guidance law.
3. Sperry 1819B model receives FCRC Guidance command (previous pass).
4. Sperry 1819B model computer Control Law command based on FCRC Guidance Input.

In the above demonstration, models were needed for aircraft guidance and control laws and also for a consistent airframe to be controlled. Although SCT had implemented a KC-135 aircraft model on the PDP-11/34, a set of compatible guidance and control law algorithms which could be run on an AN/AYK-15 did not exist. For this reason, the existing A-7D guidance and control laws, along with an A-7D aircraft model, were used for this demonstration. Conversion to the Speckled Trout EFGS and aircraft model can be accomplished in accordance with the plan presented below.

RECOMMENDATIONS/CONCLUSIONS

The following points summarize the work accomplished:

1. The integration of the Sperry 1819B with a AN/AYK-15 appears feasible.
2. Two AN/AYK-15's and a PDP-11/34 with aircraft model are in place.

Hardware and software work must be accomplished to integrate a working facility appropriate to the Speckled Trout. This work may go in either of two directions. One approach is to begin integrating the system according to the following steps:

1. Design and fabricate Sperry/1553 interface box -- FEF support group.
2. Have Sperry train Air Force personnel (FEF support group or contractors) on microprogramming of I/O channels.
3. Develop interface software for <u>basic</u> Sperry AN/AYK-15 communication over 1553 bus.

4. Restructure Sperry DFGS and accomplish functional integration with FCRC (AN/AYK-15 applications software).

Alternatively, if the facility is to be ground-based for more time and if it is to be used for algorithm analysis (rather than flight software verification), we would recommend considering a different approach. This approach is to develop a moderate fidelity, all-software model of the Sperry DFGS and implement it on one of the AN/AYK-15's. Research algorithms can be developed and run in parallel on the other AN/AYK-15. All interface communication can be done over the 1553 bus, including interface to the Speckled Trout aircraft model. Note that this could be a fairly low-cost approach, because all the hardware is in place and the system-level exec/bus control is already working. Also, the Speckled Trout aircraft is already working. Also, the Speckled Trout aircraft model has been made compatible with the FEF PDP-11/34. The major work element is the recoding of the DFGS in Jovial to run on an AN/AYK-15.

2.3.2.4 Flight Control Test Support

The objective of this task was to formulate a strawman flight test plan for the Speckled Trout aircraft. The plan was coordinated with FIGL to be consistent with research objectives in the FY80-FY81 time frame. The plan covered the following:

- Flight Test Objectives and Simulation Requirements Summary - Background material on example objectives for the collection of flight test data and development of a Speckled Trout simulation model of reasonable fidelity.
- Aircraft Modeling and Systems Identification - An overview of the overall systems identification methodology, with examples extracted from work done previously for the Office of Naval Research using the F-4S and T-2C aircraft.

- Speckled Trout Aircraft Instrumentation - A description of the current Speckled Trout data collection system, and recommended enhancements for systems identification.
- <u>Recommendtions for Preliminary Flight Test Plan</u> - Recommendations for an initial set of test conditions, test inputs, and data recording requirements to generate a set of preliminary data.

As a result of this study, specific inputs to a preliminary flight test plan for system identification of the Speckled Trout aircraft were presented and summarized below. These inputs include a definition of:

(1) Aircraft Configuration/Flight Conditions
(2) Recommended Maneuvers
(3) Data Recording Requirements

For this preliminary plan, the maneuvers focus on identifying the basic aircraft model in a cruise condition. This is done because it corresponds to the least complicated aircraft configuration, and thus is the simplest illustration of the system identification procedure. Also, the bulk of existing modeling data is oriented towards the cruise condition so that comparisons can readily be made. Basically, technical risk is minimized with this approach.

Flight test planning is always in iterative process. As the objectives change and as deficiencies are discovered in the flight data, revisions to the flight test plan can be expected. In particular, the next step in the system identification and modeling process will be to focus on specific simulation model update requirements and broaden the flight test scope to include the approach/landing configuration. At that time, additional maneuvers will be specified to study ground effect, pitch moment due to thrust changes, effect of flaps and spoilers, etc.

Note in the following that an attempt was made to make the data recording requirements to be sufficiently general so as not to require modification for future identification flight tests.

RECOMMENDATIONS/CONCLUSIONS

Aircraft Configuration/Flight Conditions

The aircraft should be established in its normal cruise configuration. The autopilot should be disengaged, except as necessary to support recording requirements via the Honeywell RL-6. The yaw damper should be disengaged, except as specified by particular maneuvers.

Prior to flight, center-of-gravity location should be measured, and all mass properties recorded.

Flight conditions should include cruise at, as a minimum, two altitudes (e.g., h1 = 30K ft, and h2 = 20K ft). The throttle should be held constant at normal cruise setting. The recommended maneuvers reported assume an initiation from trimmed cruising flight at the two specified initial altitudes. However, precisely trimmed initial conditions are not required for the system identification analysis.

RECOMMENDED MANEUVERS

An initial set of maneuvers suitable for system identification for cruising flight were detailed in a table. The table lists the maneuver number, title, identification, objective, and a description of manual inputs. As a minimum, two cruise angles-of-attack should be flown (e.g., α_1 = 3 deg, α_2 = 7 deg).

The following points are notable from the information provided in the table:

(1) A "square wave" input is preferred because it excites a broader band of frequencies than other inputs (step, sine wave).

(2) Several amplitudes and frequencies of inputs should be tried.

DATA RECORDING REQUIREMENTS

The variables which should be recorded to support system identification were also listed in the table. It is recognized that when the Sperry Autopilot is not engaged, certain of these variables may be meaningless (e.g., PHICOM, etc.) However, means must be provided to

record sensor data via the Sperry/Honeywell RL-6 regardless of autopilot mode.

Note also that recording mechanisms must be developed for angles-of-attack and sideslip and pertinent engine parameters (Items 33 through 50 in the table). In lieu of direct measurements, α and β could be calculated from NAV parameters:

$$\alpha = \dot{h} / V_{TAS}$$

$$\beta = \Psi - \Psi_{REL\ WIND}$$

However, this would require NAV data at 10-20 SPS. $\dot{H}$ would have to come from the Sperry complementary altitude filter and VTAS also from Sperry autopilot calculations. Ψ REL WIND would have to be calculated from quantities supplied by the RNAV system. All these calculations subject the α and β estimates to errors; thus raw measurements are much preferable.

2.4 FLIGHT CONTROL DEVELOPMENT LABORATORY (FCDL)

Under the ICSES contract, Systems Control Technology, Inc. provided support to the Air Force Wright Aeronautical Laboratories Flight Dynamics Laboratory Control Synthesis Branch (AFWAL/FIGD) in the areas of establishing a software management methodology and software tools to implement this methodology. The Flight Control Development Laboratory provides the developmental tools to advance flight technology and ensures that future Air Force weapon systems will be less costly, more survivable, and have superior performance characteristics. Cost-effective development of advanced aircraft is enhanced through simulation testing. Engineering flight simulation is achieved by mathematically modeling an aircraft using aerodynamic, flight control, propulsion, structural, avionic, and environmental characteristics coupled with the necessary displays and a control feel system which enables the pilot to experience the illusion of actual flight.

The Flight Control Development Laboratory contains a number of simulation facilities including the LAMARS, Multicrew Simulator, Fighter/Bomber Simulator, Crew System Integration Facility, Flight Control Actuation and Hydraulics System Facility, and two in-flight simulators (T-33 In-Flight Simulator and the Total In-flight Simulator).

The Large Amplitude Multimode Aerospace Research Simulator (LAMARS) consists of a five-degree-of freedom beam type motion system which carries a single-place cockpit and display screen on the end of a 30-foot beam. The motion base produces motions at the pilot's station in precise phase and amplitude corresponding to the signals under computer control. The on-board visual display system utilizes a wide angle, ten-foot radius, spherical projection screen that provides the pilot with a visual representation of the outside environment. The cockpit design is compatible with all modern fighter aircraft configurations and can be readily adapted to different configurations.

The Multicrew Simulator and Fighter/Bomber Simulator are also motion base systems. The cockpit controls, configuration, and instrumentation may be readily modified as required. The control feel

system, with either a wheel/column or center stick can be programmed with desired characteristics. Both systems carry a DUOVIEW visual display system to enhance the realism of the simulation task. Both cockpits have multi-degree of freedom scissors type motion systems. The Multicrew Simulator has three degrees of freedom: pitch, roll and heave. The Fighter/ Bomber Simulator has five degrees of freedom, adding lateral translation and yaw to the three previously mentioned.

A Rigid Model Visual System (RMVS) is also used which consists of illuminated three-dimensional terrain models, each with an optical-probe-equipped television camera positioned by precision servo systems commanded by computer control. The LAMARS, Multicrew, and Fighter/Bomber Simulators all make use of this RMVS.

A hybrid computing system forms the nucleus of the simulation equipment and consists of digital and analog-computers. The computing system also has peripheral equipment including card readers, line printers, terminals, magnetic tape units, and eight-channel recorders and x-y plotters. A summary of this computing system is shown in Figure 2.4-1.

The Crew-System Integration Facility contains static crew station models that provides a cost-effective means for determining design criteria such as crew size, control and display arrangement, display formats, and crew procedures.

The Flight Control Actuation and Hydraulics System Facility contains equipment used to develop and test servoactuator that provide the essential link between cockpit controls and aircraft control surfaces.

The T-33 In-Flight Simulator and the Total In-Flight Simulator provide an element of realism to simulation which is impossible to obtain in ground based simulation activities. In-flight simulation can provide realistic sustained motion cues and an outside visual scene.

2.4.1 Support Requirements

The evolution of the FCDL is not unlike that of many other simu-

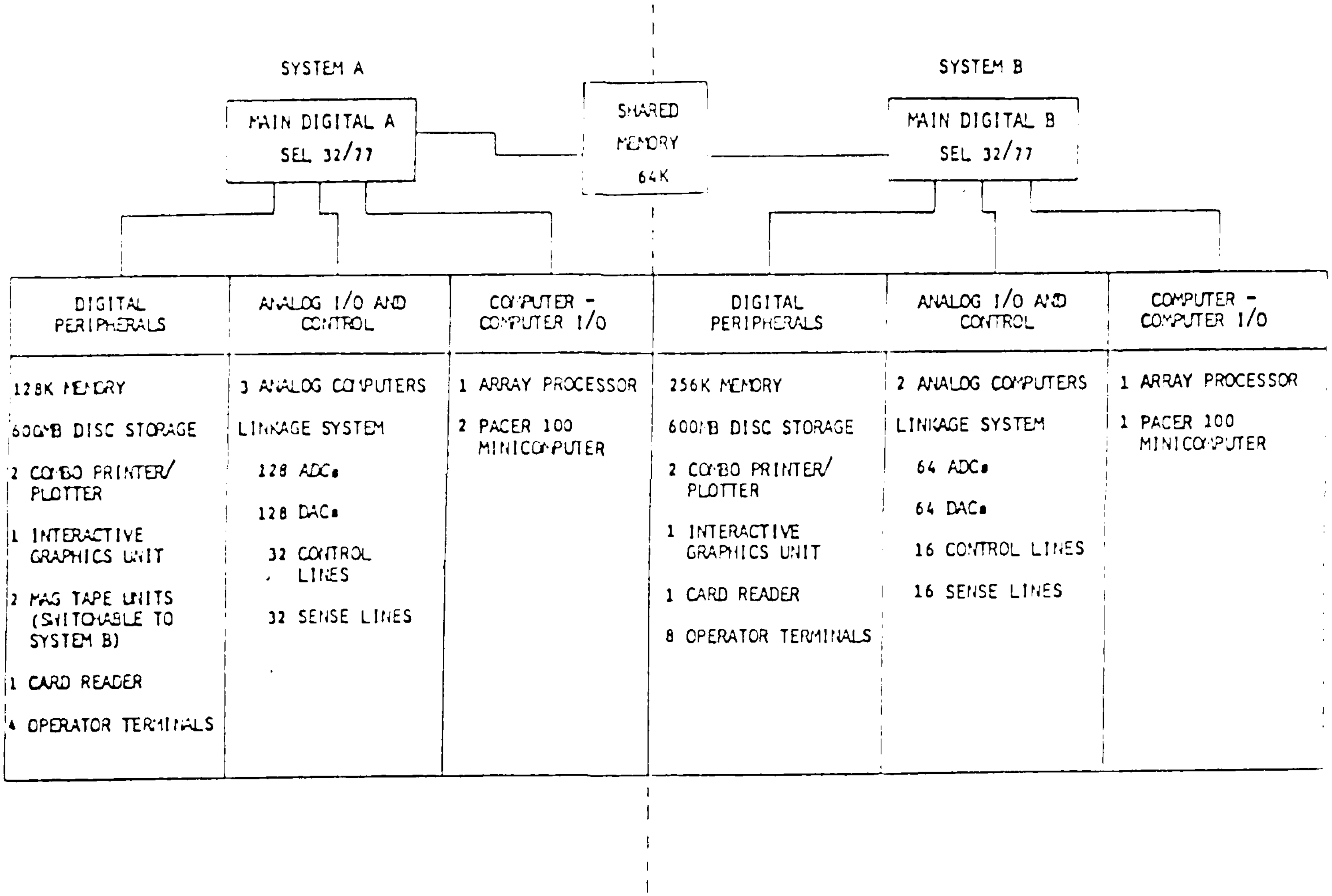


Figure 2.4-1 AFWAL/FI Real-Time Hybrid Computer System

lation facilities, and common problems can be seen to have arisen. Today, the FCDL serves a number of varied users, ranging from inhouse activities, to other FDL groups (ADPO's, etc.), to nonmilitary users such as the F.A.A. Simulations are developed to represent a number of different aircraft performing increasingly complex, multi-role missions. Expansion and modernization of hardware and related software happen on a continuing basis. Software and hardware interface requirements between different programs may be implemented differently by design or by necessity. Software of many types (real-time simulation models, off-line support software, post-run data reduction software, etc.) had proliferated to the point where FIGD did not know exactly what software existed or how it might be reused. Software maintenance was difficult, including both the long-term ability to retrieve archival programs for re-use and also the continual maintenance of current systems on a systematic basis. Personnel turnover further complicated these problems in that it was difficult for new personnel to absorb the simulation development techniques and their unawareness of software which already existed caused much duplication of effort. Many of these problems could be traced to inadequate control of the software development process and the resulting absence of adequate documentation. Since particular software management requirements vary from facility to facility, an in-depth examination of the FCDL software development methods was performed by talking with numerous FCDL personnel. The information collected in these interviews was integrated into the following areas: software, firmware/hardware, configuration control, project management, training/indoctrination, customer interaction, and vendor interaction.

Each of these problem areas were then mapped in requirements to be addressed in the ensuing development of a software management methodology. This entire analysis is contained in SCI Document #80-FCDL-09 Rev. A, "Software Management Methodology Requirements Analysis", 30 June 1980. A summary of the identified requirements is presented below.

<u>Project Management Requirements</u>

Establish project management practices and procedures which will:

perform the simulation development effort in the most direct, efficient and controllable manner; provide short clear lines of communications; permit concentration of the appropriate technical skills; provide complete visibility to FIGD management throughout the development, test, and integration phases. In short, project management involves all facets of simulation development, establishing guidelines, managing and coordinating activities, and insuring the program requirements are met in an expeditious manner.

Software Development Requirements

Establish scftware development methods and procedures that will produce accurate, efficient, readable, maintainable, and well documented software programs. These methods and procedures will address software development from the requirements phase through validation and applications.

Indoctrination and Training Requirements

Establish the mechanism for indoctrination and training of personnel in regards to the software management methodology. This may include recommendations for vesting particular parts of the FIGD organization with the authority and responsibility to: develop procedures to indoctrinate personnel in task management, configuration management and developmental standards; train new personnel in the use of configuration management library and other technical resources; develop instructional material in applicable software engineering practices.

Configuration Management Requirements

Establish configuration management procedures which will (a) identify and document the functional and physical characteristics of the simulation software; (b) control changes to those characteristics; and (c) record and report change processing and implementation status. In particular, the procedures should address: configuration management organization and authority for software control; establishment of a configuration management (CM) plan which implements CM organization, library and resouces in a phased manner; establishment of configuration control procedures; status accounting of all controlled items; procedures for review and audit; guidelines

and procedures for managing obsolete software in the CM library; procedures for deciding what software is subject to CM, and which is not; and identification of product support software needed to implement fast, responsive configuration management.

2.4.2 Work Accomplished

Having performed requirements analysis to identify the type of support which would best meet the needs of FIGD, a two phased effort was defined to meet these requirements. The two phases were (1) development of Software Management Methodology and (2) design/development of software tools for support of this methodology.

2.4.2.1 Software Management Methodology

A software management methodology was developed which addressed all aspects of software development, from initial software planning to software control and maintenance. This methodology was presented in four separate volumes of software standards, consisting of Software Management Standards, Software Development and Test Standards, Software Documentation Standards, and Software Configuration Management Standards.

Standardization of software management is necessary to achieve the following objectives:

- Reduce resource expenditures in software development
- Improve software development resource estimating
- Avoid duplicate software development efforts
- Improve quality of software
- Reduce software maintenance efforts

A disciplined software development process can be broken into three phases: Preliminary Design Phase, Detailed Design Phase, and Implementation and Test Phase. These phases are depicted in Figure 2.4-2. These three phases follow naturally from the activities performed in the development of any software product. Each phase

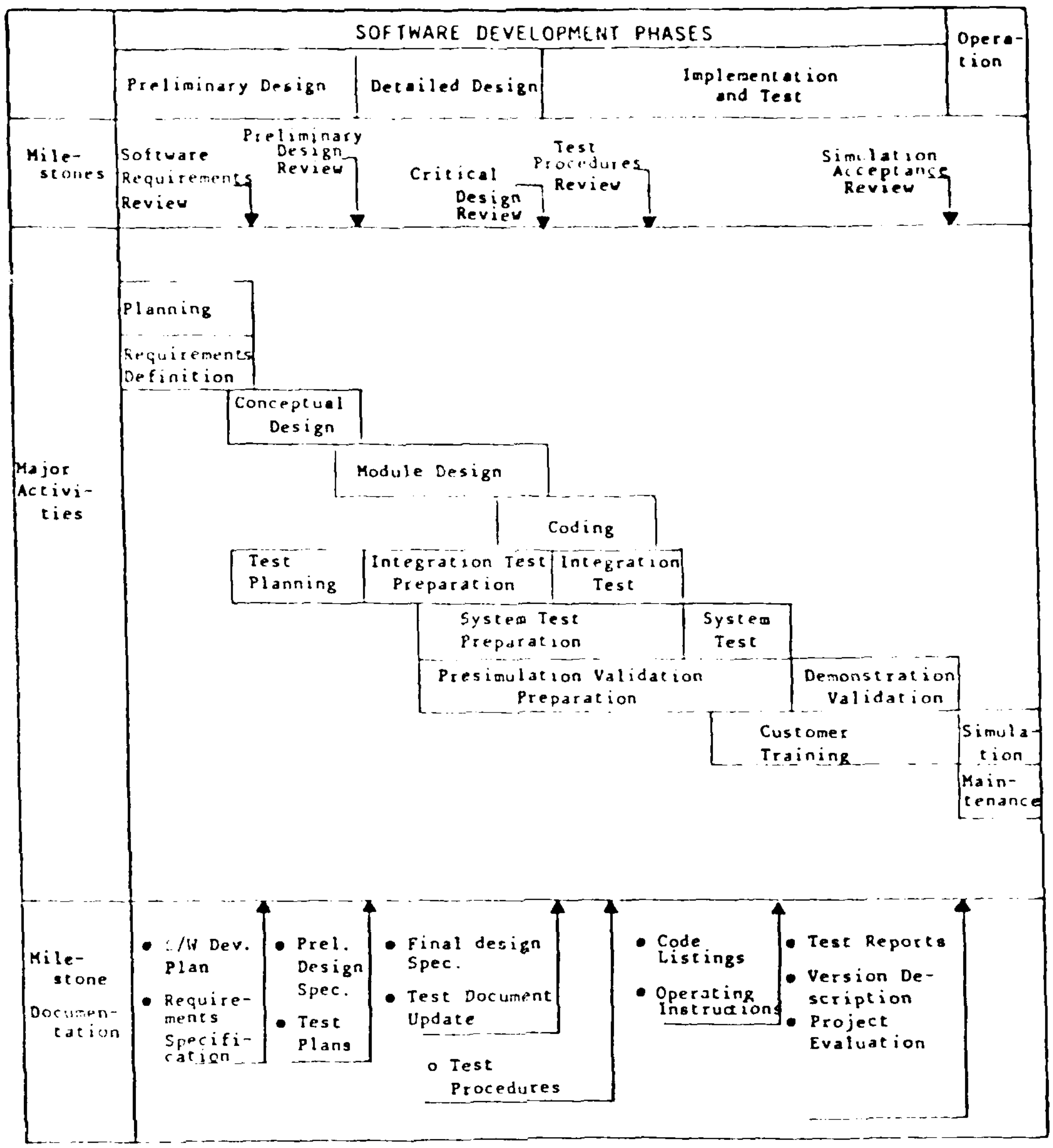


Figure 2.4-2 Software Development Phases

contains milestones used by management as breakpoints to monitor and review the progress of the development effort. Within each of these phases specific activities are defined and specific outputs are produced which allow both managerial and technical review of the software development (see Figure 2.4-2).

During the Preliminary Design Phase, a software development plan is written, the software requirements are defined, external interfaces are identified, a conceptual software design is achieved and a plan for testing simulation software against requirements is written. Within this phase, all performance and external interface requirements are documented prior to the conceptual software design and are reviewed at a Software Requirements Review (S/WRR). The conceptual design and test plan are documented during this phase and reviewed at a Preliminary Design Review (PDR).

The Detailed Design Phase starts after the PDR. During this phase, interfaces between all simulation software components are defined in detail, the software components are designed and documented, and preparations for integration, system, and presimulation testing are initiated. The documents prepared are then reviewed at a Critical Design Review (CDR).

During the third phase, Implementation and Test, computer program code is written and checked individually and then integrated to form the simulation software. Test procedures for development testing are documented and reviewed at the Test Procedures Review. During testing, test results are documented as required, instructions for operating the simulation are documented, plus a list of the simulation hardware and software is prepared. A summary of the software milestones and related activities is shown in Figure 2.4-3.

The software standards which were prepared can be applied to the development of any size software program, but have been tailored to meet the needs of the FIGD software development team. As shown in Figure 2.4-4, the Software Management Standards control the use of the Software Development and Test Standards and Software Configuration Management Standards. Application of the Software Development and Test Standards yields software products which conform to quality

Time Period and Activities	Milestones
Project Initiation to S/WRR Project Selection Software Development Plan Software Requirements Definition Requirements Change Control	Software Requirements Review
S/WRR to PDR Software Development Folder Initiation Software Conceptual Design Software Test Planning	Preliminary Design Review
PDR to CDR Detailed Design Definition Operating/Version Document	Critical Design Review
CDR to TPR Coding Unit and Module Testing Integration Testing Design Change Control Operating/Version Document Update Software Test Document Update	Test Procedures Review
TPR to SAR System Testing Release of Software Documentation Presimulation Validation Software Development Evaluation Records Disposition Simulation Maintenance	Simulation Acceptance Review

Figure 2.4-3 Software Development Activities and Milestones

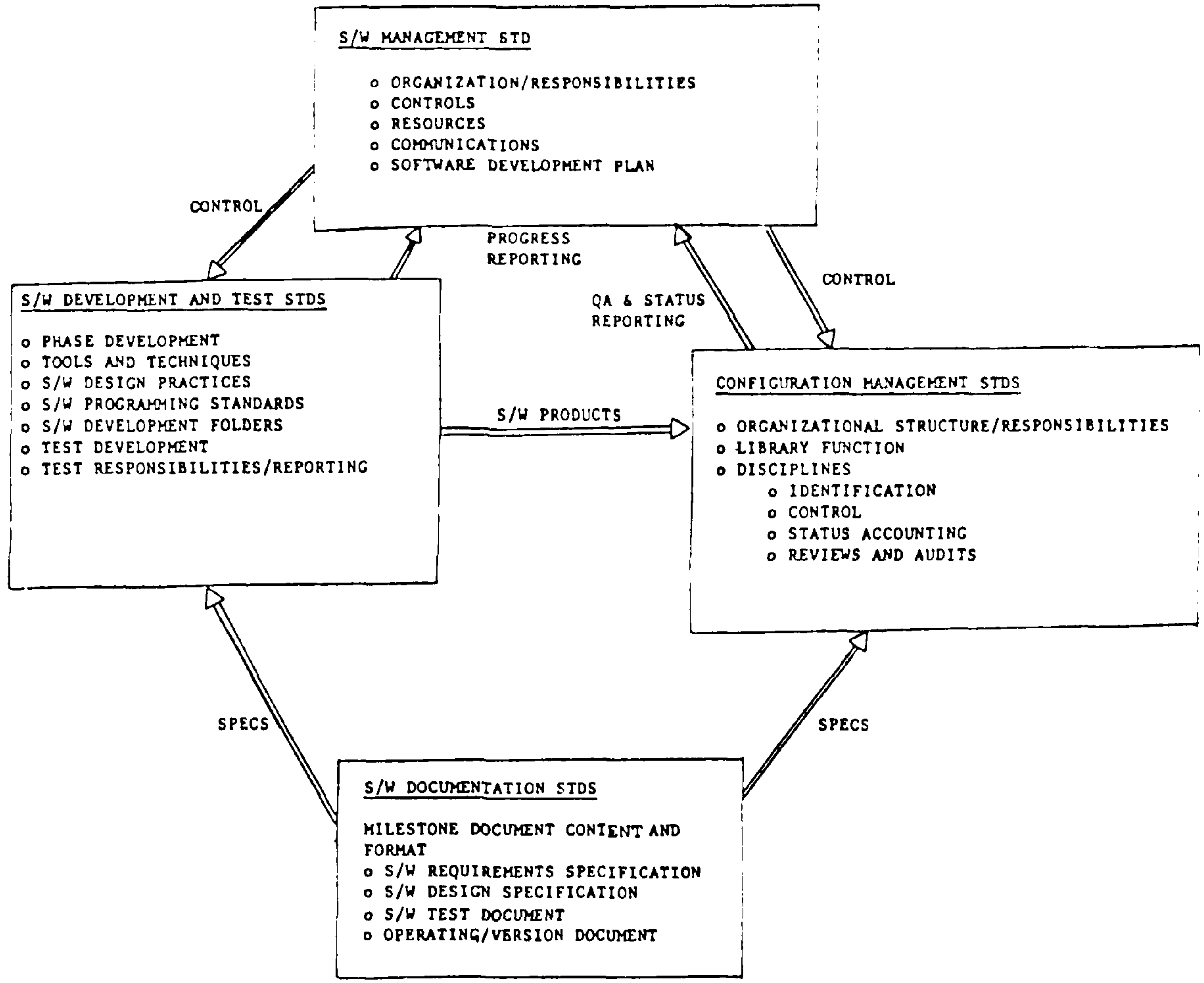


Figure 2.4-4 Software Standards

assurance provisions and controls established by the Software Configuration Management Standards. The Software Documentation Standards establish the format and content of the four milestone documents. Each of the software standards is summarized below.

Software Management Standards

The Software Management Standards provides FIGD software managers with procedures and guidelines for planning and managing simulation software development.

The standards describe the duties and responsibilities associated with each function performed by the software development team during each phase of software development. The management standards contain a description of the software development process and a summary of all software standards.

Software Development and Test Standards

The Software Development and Test Standards provide engineering and programming guidelines to preliminary design, detailed design, and implementation and test activities. These standards describe the activities to be performed during each development phase. Activities described are simulation software requirements definition, conceptual design, detailed design, coding, checkout, and testing. These standards also describe the tools and techniques that are used. Examples of tools and techniques are: flow charts, data flow diagrams, programming languages, and data base dictionaries.

Software Documentation Standards

The Software Documentation Standards provide formats and guidelines for four documents required in the software development process.

The documents to be produced for each software development have three main purposes:

- To provide information for communication and management control of the entire development process.
- To provide baselines for further development and maintenance of the software.
- To provide evidence at all stages of the process that the software being developed meets specific functional

requirements and schedules.

Each of the 4 software documents addresses particular documentation requirements as follows:

1. Software Requirements Specification: Specifies the functional, performance, external interface, and design requirements for the simulation software to be developed.
2. Software Design Specification: Specifies the simulation software design including all internal interfaces and module detailed design.
3. Software Test Document: Presents a simulation software test plan, test procedures, and test report for the different levels (module, integration, system, and presimulation validation) of software testing.
4. Operating/Version Document: Consists of two major sections - Operating Instructions and a Version Description. The Operating Instructions tell how to execute the simulation software. The Version Description lists all software elements, hardware elements, and supporting documentation needed for simulation execution and maintenance and contains a record of all software changes subsequent to acceptance testing.

Figure 2.4-5 illustrates the development and flow of data for the design, integration, and test of a typical computer program. The development of the 4 documents is shown by the numbered triangles "△#" The repeated occurrence of △2, △3, and △4 indicates incremental development of the Software Design Specification (△2), Software Test Document (△3), and Operating/Version Document (△4).

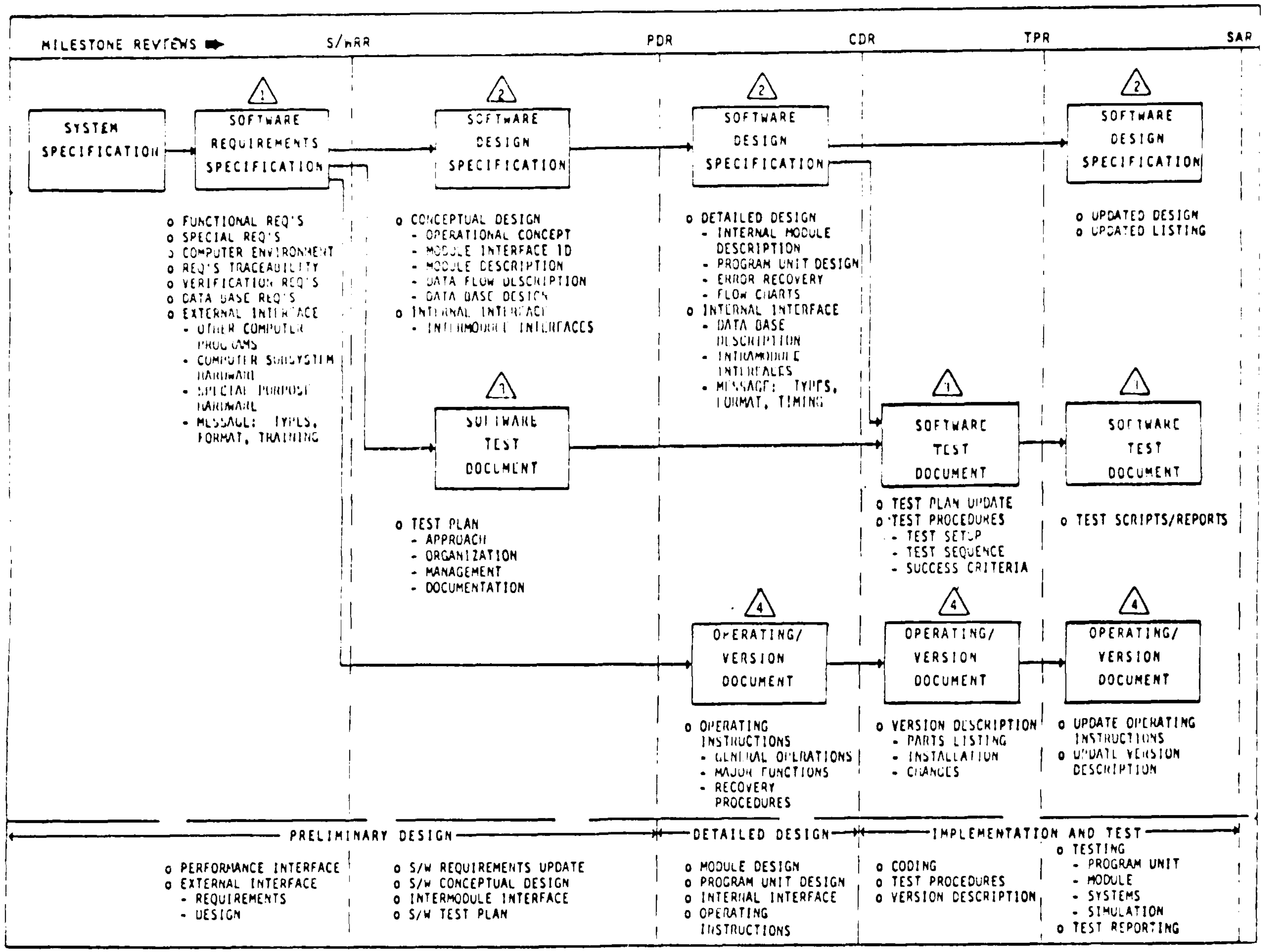


Figure 2.4-5 Software Document Data Flow

Software Configuration Management Standards

The Software Configuration Management Standards provide guidelines for change classification and control, configuration accounting, and the conduct of reviews and audits. The function of configuration management will provide for operating and maintaining a computer program library, for filing and processing all software problem reports (SPRs) and specification change notices (SCNs), and coordination of simulation software maintenance.

These standards were initially presented to AFWAL/FIGD in the form of briefings/tutorials to familiarize FIGD personnel with the basic concepts and procedures. Following the briefings, the Management Methodology Standards were released for review and use.

2.4.2.2 Software Management Support Tools

The second phase of the support consisted of developing two software support packages, one to be used by FIGD in controlling developed software and the other to tracking FCDL documents. These software programs were the Computer Program Library Catalog (CPLC) Software and the Documentation Tracking Program (DTP) software.

Computer Program Catalog Software

The objective of the CPL catalog software is to help the configuration management office (CMO) manager of FIGD maintain inventories of software documents and products, and status logs on change requests (CRs) and specification change notices (SCNs). It provides a means to set up, change, obtain information, or delete such catalogs as needed.

Three different catalog files formats are available to support CMO activities: inventory, CR status log and SCN status log. Each format defines the organization of catalog entries into data fields and provides a text header that can be used for printouts and displays. Four general ideas characterize the CPL catalog software:

a) It provides the basis for creating and maintaining inventories and status logs pertaining to FIGD configuration managed software.

b) It provides means of printing or displaying entries

or groups of entries from a catalog file.

c) It may be used by clerical personnel assigned to the CMO as well as experienced simulation engineers and programmers.

d) Access to inventories and status logs is controlled by means of passwords, and "read-only" and "read-write" privilege levels.

The CPL catalog software is written in FORTRAN 77 and operates on the SEL 32-77 computer system using an MPX operating system. This software is currently resident on the AFWAL/FIGD SEL32-77 computer system.

Architecturally the CPL catalog software provides an interface between a human user and the various disk files, displays, and printers required to produce or use various CMO catalogs. The interface to the user provides the user with instructions and commands necessary to create and update a catalog file, including:

a. Set-up a new catalog file (i.e., inventory or status log).
b. Access an entry in a catalog file.
c. Create an entry in a catalog file.
d. Modify an existing entry in a catalog file.
e. Delete an entry from a catalog file.
f. Delete a catalog file.
g. Print or display data from a catalog file.
h. Copy or rename a catalog file.
i. Print instructions on how to use this software.

Other architectural elements are also included to provide access to internal system resources: disk files, printing equipment, and displays. The complete design of the CPLC software is documented in the Computer Program Library Catalog Software Design Specification, SCT Document #81-FIGD-005, 8 May 1981.

Documentation Tracking Program (DTP) Software

The Systems Operations Group of AFWAL/FIGD maintains a large,

hybrid computer facility. This facility is supported by a large number of manuals and drawings which from time to time are revised to reflect the current system configuration. Because of the large number of documents, many of which have been distributed to various engineers, a need exists to be able to track the various document revisions already distributed. The purpose of the DTP software is to provide a user-friendly software tool that will aid in the document tracking task.

The DTP Software is written in Fortran 77+ and operates on the SEL 32-77 computer system using the MPX operating system.

The program is used to inventory AFWAL/FIGD documentation. Inputs to the inventory file entries for each document include the following:

a) Document Title
b) Publication number
c) Edition or revision number
d) Publication date
e) Total number of copies
f) Owner and number of copies
g) First key word
h) Second key word
i) Short description

The program makes use of permanent files and a temporary or working file - used to hold changes and additions. If changes are made to a file the DTP software will copy the permanent file to a backup permanent file. The program then writes the updated working file to the permanent file.

The DTP software recognizes six commandes used to aid the user in maintaining the document data. They are:

HELP - User instructions
ADD - Adds new entries to the file
MODIFY - Modifies an entry
DELETE - Deletes a specified entry from the file
LIST - Displays entries from a catalog

END - Closes all files and returns to monitor

The add, modify and delete commands are password protected which means the user must enter the correct password to use these commands.

Four SCT documents listed below were generated during the development of this software.

- Documentation Tracking Program Requirements, SCT #5336-421-3, 7 July 1982
- Documentation Tracking Program Design Document, SCT #5336-421-5A, 30 Sept 1982
- Documentation Tracking Program Operating Instructions, SCT #5336-421-4, 30 Sept 1982
- Documentation Tracking Program Software Test Document, SCT #5336-421-6, 30 Sept 1982

2.4.3 Conclusions and Recommendations

AFWAL/FIGD was similar in ways to many other software and simulation development facilities. Many facilities began either in support of single projects or as small operations staffed by a select group working closely together. As long as that situation persisted, problems were few. As the number of separate programs using the facility increased, so did the size and complexity of the facility. Software of many different types was developed. Often, software documentation practices were inconsistent or absent and reuse of software was limited. With the advent of new, more capable computers, the number of users of a facility increased but there was not a corresponding increase in personnel to support their users. Often during development, as deadlines approached, communications broke down, coding was the highest priority task and documentation was an afterthought. Although the finished program worked, it was generally not up to desired standards with respect to readability, maintainability, and documentation.

The Software Management Methodology which SCT developed in close concert with FIGD was aimed at eliminating most of these problems.

The software tools developed by SCT served as an aid in implementing some of the methodology. However, successful implementation of a software management methodology requires a commitment on the part of AFWAL/FIGD top management. In additon, successful implementation of a sofware management methodology depends on its acceptance by the work force. The work force was involved in its design as an initial step, but this should be followed up by a consultation and tutorials. Along these lines, the establishment of a core of experienced individuals, well indoctrinated with the software management procedures, is essential in providing the continuity needed for successful software implementation.

2.5 CONTROL SYSTEMS ANALYSIS TASKS

2.5.1 Avionic/Flight Control Reconfiguration

2.5.1.1 Background and Goals

The purpose of this study was to examine strategies for increasing the reliability of integrated control of flight systems through reconfiguration, particularly the concept of virtual redundancy. Virtual redundancy, possible in highly integrated avionics/flight control system architectures, involves the reconfiguring of system resources so as to create redundancy on demand.

The virtual redundancy concept is illustrated in Figure 2.5-1. Before any processor failures, functions may be assigned to processors as indicated in the upper half of the figure. Upon detection of a failure of one of the processors assigned to flight control (for example), the assignment of functions may be redistributed as indicated in the lower half of the figure.

Integrated control of flight implies a high degree of dynamic coupling between avionics and flight control. Accordingly, much current emphasis is being placed on highly integrated, bus-oriented architectures and bus topologies which exhibit a high degree of connectivity between flight control and certain avionics function (e.g., Integrated Fire/Flight Control, Integrated Flight/Trajectory Control, Terrain Following/Terrain Avoidance, etc.).

The Reconfiguration Study, along with its successor experiments, attempted to exploit this high degree of architecture integration and bus connectivity to enhance "coverage" and to recover lost critical functions.

"Coverage" is the ability to detect, isolate, and accommodate or recover from failures. If coverage is sufficiently effective, systems with reduced hardware redundancy can exhibit abort or loss-of-control probabilities comparable to higher redundancy systems which have lesser coverage. The sensitivity of system reliability is illustrated in Figure 2.5-2 for the case of duplex systems. Typically, coverage

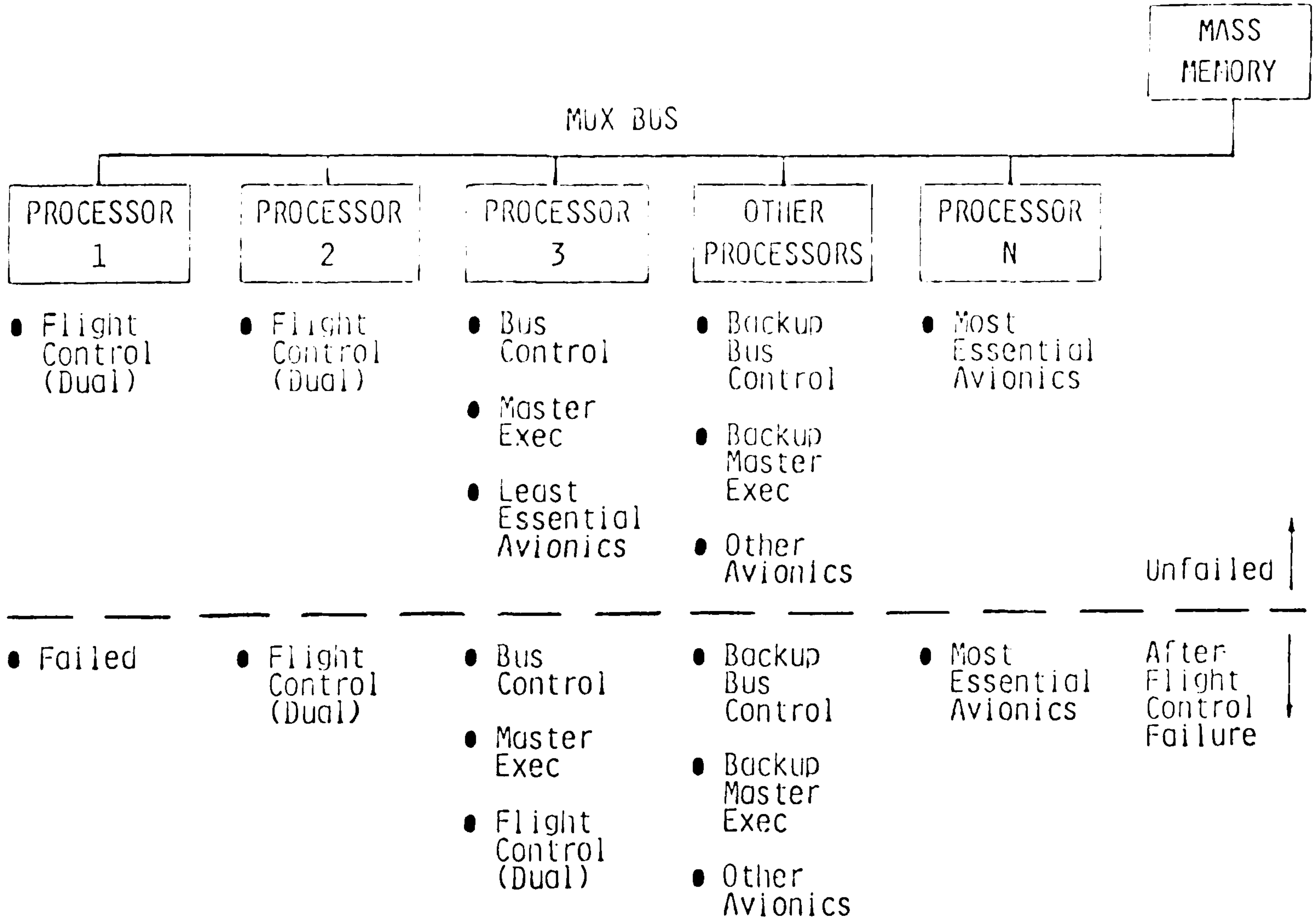
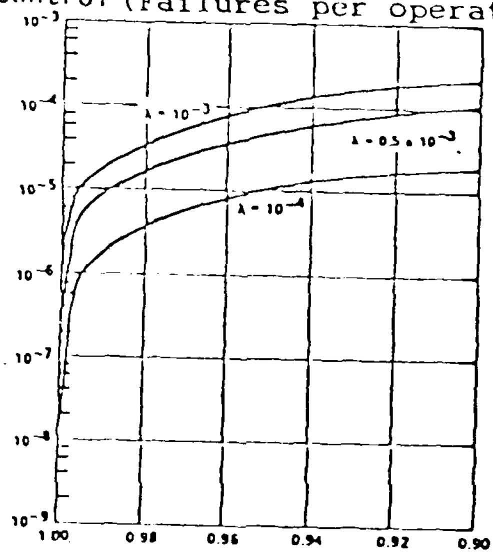


Figure 2.5-1 Reconfigurable Avionics/Flight Control Concept

Probability
of loss of
Control (Failures per operating hour)



Monitoring Coverage (%)

λ = Fail Rate

Figure 2.5-2 Importance of Fault Coverage (Duplex System) [1]

is provided either by in-line monitoring (self-test, etc.) or cross-channel monitoring (voting) techniques. Of course, cross-channel voting requires at least three valid voters for fault isolation.

A unique aspect of the Reconfiguration Study is examination of virtual redundancy as a means of fault isolation for cross-channel monitoring when only two signals (for example, flight control processor computed outputs) are present. In this case, fault detection is provided by a persistent miscompare of the two signals. Fault isolation if not successfully performed by self-test or other in-line techniques, can be accomplished (for example) by causing an avionics processor to perform a "backup" flight control solution on demand. This third signal can be used to break the tie concerning which flight control processor has failed. Recovery can be effected by dynamically loading a spare or lease essential processor with flight control laws (again for this example). The replacement processor must then be initialized so as to ensure its smooth and rapid inclusion into the redundancy management scheme.

Recovery of lost functions as described above is of particular importance for longer mission durations, such as that examplified by the Long-range Combat Aircraft.

2.5.1.2 Study Objectives and Scope

The major objective of the Reconfiguration Study was to provide, through laboratory demonstration, a general assessment of the feasibility of virtual redundancy and system reconfiguration to enhance coverage and recover functions lost due to failures. The assessment was oriented towards the identification of architectural design issues and the resolution of these issues in favor of (1) ease of integration and (2) minimization of hardware, which are primary goals.

The scope of the study included:

(1) The identification and analysis of design issues;

(2) The definition of a candidate architecture;

(3) The implementation of the architecture in a

laboratory environment; and

(4) The collection of quantitative data regarding the impact of reconfiguration on system performance.

Several groundrules were adopted in the approach to the study to limit the scope realistically. These are summarized as follows:

(1) Candidate architectures should be sufficiently fault tolerant that a single processor failure does not result in loss of mission and a double processor failure does not result in loss of aircraft;

(2) Architectures considered should be bus-oriented with high connectivity (flight control and avionics on the same bus);

(3) Hardware and software developed in the DAIS program should be used for laboratory evaluation where possible, with software modification as necessary.

2.5.1.3 Study Approach

The approach to the Reconfiguration Study was issue oriented, focusing on the primary issues of executive interplay between processors; bus loading/bus control; failure detection, isolation, and recovery (reconfiguration); and transient effects. As mentioned previously, the study attempted to utilize the DAIS architecture and executive software where possible, and to make necessary modifications where practical and to indicate where further capability of the DAIS approach is recommended.

The study consisted of three major tasks:

(1) Conceptual Analysis and Architecture Selection;

(2) Development of a Functional Emulation Tool; and

(3) Laboratory Evaluation.

These tasks addressed reconfiguration issues as shown in Figure 2.5-3. The purpose of the conceptual analysis (Task 1) was to perform analysis necessary to focus the remainder of the study on the minimum complexity architecture that is capable of demonstrating the reconfiguration concept. Task 2 developed a functional emulation of the

METHOD OF STUDY / DESIGN ISSUE	CONCEPTUAL ANALYSIS	FUNCTIONAL EMULATION	LAB EVALUATION
EXECUTIVE INTERPLAY	✓	✓	✓
BUS LOADING/BUS CONTROL	✓		✓
FAILURE DETECTION	✓	✓	✓
• Persistence		✓	
• Thresholds		✓	
• IFIM	✓		
• Time-To-Detect		✓	✓
FAILURE ISOLATION	✓	✓	✓
• Stimulation Test	✓		
• Time-To-Isolate		✓	✓
FAILURE RECOVERY (Reconfiguration)	✓		✓
• Loading (Time-To-Load)			✓
• Initialization After Reload			✓
TRANSIENT EFFECTS	✓	✓	✓
• Duration		✓	✓
• Magnitude		✓	✓
• Impact on FC and SOF	✓	✓	
ALTERNATIVE ARCHITECTURES	✓	✓	
SYNCHRONOUS Vs ASYNCHRONOUS	✓	✓	

Figure 2.5-3 Methods Applied to Study of Design Issues

candidate architecture. This emulation was designed to have the capability to study issues which are not addressable in the laboratory, either because of hardware limitations or because modifications to the DAIS executive would be too extensive to be practical. The objective of Task 3, Laboratory Evaluation, was to demonstrate the reconfiguration concept in a laboratory environment and to collect preliminary quantitative data on the (1) impact of the MIL-STD-1553 data bus on reconfiguration; and (2) impact of the reconfiguration concept on flight control and safety of flight.

2.5.1.4 Work Accomplished

The work accomplished in this task is summarized below:

1) Adapted to the Flight Engineering Facility a multiprocessor System Exec from the DAIS Exec and associated support software.
2) Integrated a multiprocessor avionics/flight control architecture with real-time simulation capability.
3) Devised a workable method for employing virtual redundancy and reconfiguration concepts for applications which are tolerant of reduced update rates or temporary suspension of output command (i.e., highly stable aircraft).
4) Established ability to load a processor over 1553 bus and restart.
5) Established ability to dynamically initialize a processor.
6) Collected preliminary data on time-to-load over bus and time-to-initalize/recover.
7) Developed all-S/W simulation tool for analyzing alternative algorithms and architectures.
8) Identified limitations of and problems with existing laboratory hardware and software (Exec) which were GFE for this study.

2.5.1.5 Conclusions and Recommendations

The Reconfiguration Study has come a long way towards proving the feasibility of the concept of virtual redundancy and reconfiguration as a means of increasing the reliability of integrated avionics/flight control systems. Moreover, the laboratory hardware and software and support software (e.g. Functional Emulator) are now in place to pursue experiments which will thoroughly explore implementational considerations. Recommendations for future study are listed below:

(1) Incorporate software modifications to the down-loading function to allow a processor other than itself to initiate the down-load. This is a limitation of the existing Exec/Bootstrap Loader.

(2) Investigate adding the capability to down-load "dynamically," i.e., without having to halt other processors. In the current laboratory configurations, the output to the control surface is essentially frozen during the reconfiguration process. This is necessary because the current System Exec cannot handle reload/bootstrap and normal operations simultaneously. The capability to allow known good processors to control the aircraft during reconfiguration needs to be added in future experimentation.

(3) Add a third processor to the demonstration configuration. This will enable study of systems of dual flight control redundancy and will also enable study of backup System Exec.

(4) Streamline the System Exec to make it more practical for flight control applications. Currently, emphasis on the Exec design is towards flexibility; certain nonessential functions could be removed to greatly improve efficiency and make the Exec more credible in the flight control application.

(5) Develop techniques for monitoring and backup of the System Exec so as to enhance reliability of the overall system. Non-stationary Master (bus control) approaches should be examined.

(6) Investigate higher levels of bus redundancy as a means to increase overall system reliability and to improve data throughout.

2.5.2 Multivariable Control of Wingshape

2.5.2.1 Background and Goals

Demonstration of the mission-adaptive wing (MAW) technology, also called "smooth variable camber" (SVC), is an objective of the Air Force's Advanced Fighter Technology Integration Program. The performance, control, and mission effectiveness benefits for an aircraft with a smooth variable camber wing will be demonstrated by the AFTI/F-111 airplane. The design objective is to use the variable wing camber to optimize the wing's aerodynamic efficiency over a broader speed range and to provide additional control devices. Potential applications for the variable camber wing are presented in Table 2.5-1, which shows the control function, the relative control bandwidth (i.e., how fast the flaps must move) and considerations for integration of the camber control function with other flight control surfaces. The actual mix of control functions is dependent on the type of aircraft and its mission as shown in Table 2.5-2.

Acceptance of SVC or the MAW as a viable aircraft design technique is contingent on a demonstrated capability to establish wing camber which is fully consistent with the dynamics, speed, and current flight conditions. Unless this is an automatic capability, the pilot's workload could become unacceptably high. He would need to refer to wing performance charts, select the most appropriate configuration, and then appropriately set each of the flap deflections. While this may be an acceptable procedure for high-altitude, steady-state cruise, it cannot be considered for low-altitude maneuvering flight (e.g., terrain-following and avoidance).

At this time, demonstrated techniques to set wing camber automatically do not exist and development of this capability must be considered a priority need. Thus, under the current AFTI F-111 con-

Table 2.5-1 Wing Camber Control Applications

PRIMARY FLIGHT CONTROL FUNCTION	CAMBER CONTROL REQUIREMENT	RELATIVE CONTROL BANDWIDTH	FLIGHT CONTROL SYSTEM INTERFACE CONSIDERATIONS
• GUST LOAD CONTROL	• UNLOAD WING WITH TE DEFLECTIONS	• HIGH-SHORT PERIOD FREQUENCIES	• COORDINATE WITH PITCH CONTROL TO MINIMIZE Q GENERATED LOADS • COORDINATE WITH OTHER CAMBER CONTROL REQUIREMENTS
• LATERAL CONTROL	• DIFFERENTIAL CONTROL BETWEEN LEFT AND RIGHT WING	• HIGH-ROLL TIME CONSTANT	• SHARE CONTROL POWER WITH SYMMETRIC COMMANDS-CONTROL GAIN MIGHT VARY WITH CONTROL POSITION • BLEND CONTROL WITH DIFFERENTIAL STABILON
• DLC FOR TERRAIN FOLLOWING	• VARY CAMBER TO INCREASE/DECREASE WING LIFT	• HIGH-SHORT PERIOD FREQUENCIES	• COORDINATE WITH PITCH CONTROL TO QUICKEN FLIGHT PATH RESPONSE FOR STICK INPUTS
• DLC FOR IN FLIGHT REFUEL	• VARY CAMBER TO INCREASE/DECREASE WING LIFT	• MODERATE-FLIGHT PATH CONTROL	• COORDINATE WITH AUTO THROTTLE AND PITCH CONTROL FOR PRECISE DECOUPLED SPEED-ALTITUDE CONTROL
• L/D OPTIMIZATION - CLIMB - CRUISE	• VARY CAMBER (CHORD-WISE & SPANWISE) TO MAXIMIZE L/D	• LOW	• COORDINATE WITH AUTO THROTTLE AND PITCH CONTROL FOR REQUIRED V, α, γ CONTROL
• MANEUVER LOAD CONTROL	• VARY TE CONFIGURATION TO SHIFT CENTER OF LIFT INBOARD	• LOW	• COORDINATE WITH L/D, LATERAL AND DLC FUNCTIONS

Table 2.5-2 Wing Camber Control Requirements per Aircraft Type

PENETRATING BOMBER	LARGE TRANSPORT & CRUISE MISSILE CARRIER	FIGHTER
- HIGH SUBSONIC, HIGH q FLIGHT	- MAXIMUM RANGE	- MAX. RANGE
- TERRAIN AVOIDANCE/FOLLOWING	- MAXIMUM RATE OF CLIMB	- MAX. RATE OF CLIMB
- RIDE CONTROL & GUST LOAD CONTROL	- WING ONLY LATERAL CONTROL	- MAX. ENERGY
- MANEUVER LOAD CONTROL	- HIGH LIFT, LOW LID & LATERAL CONTROL FOR APPROACH & LAND	- INFLIGHT REFUEL - TERRAIN AVOID/FOLL
- INFLIGHT REFUEL & MAX. ENDURANCE	- MANEUVER LOAD CONTROL	- MANEUVER ENHANCEMENT
- MAXIMUM RANGE	- GUST LOAD CONTROL	
- HIGH ROLL ACCELERATION	- MAXIMUM ENDURANCE (CMC)	
	- PLATFORM STABILITY (CMC)	

tract, two approaches to automatically control wing camber are being investigated; namely, "preprogrammed" and "self optimizing." However, identified weaknesses of each of these control modes suggest that research and development in this area continue to enable SVC benefit realization.

The "preprogrammed" camber control mode is expected to provide reasonably rapid, accurate and stable wing camber settings. However, implementation of this mode may impose rather significant hardware, test, and deployment penalties. For an aircraft such as the F-111, this mode would impose significant computer memory requirements to store symmetrical control surface pair setting data for a wide range of airspeeds and wing sweep positions throughout the operating envelope in redundant computer memories. Also, performance and benefits of this mode would be directly related to the extent and accuracy of the aerodynamic performance data of the wing. This condition has the undesirable implication that, in a given mission aircraft design, extensive wind tunnel and flight testing would be required to establish an adequate control model. Accuracy of these data would be subject to stores combinations and any subsequent changes in the wing may require retesting, control system reprogramming, and safety recertification.

An automatic, "self-optimizing" camber control technique may conceivably overcome these concerns. Several adaptive techniques have been suggested and the one selected for tne AFTI F-111 demonstration employs longitudinal velocity changes as the feedback parameter. Incremental airspeed changes will be used to assess, in flight, whether MAW control surface position changes improve wing efficiency. Although this mode may overcome some disadvantages of the preprogrammed camber setting technique, its weaknesses are also significant. For example, dynamic errors in an altitude hold loop, thrust variations or airmass instabilities, such as turbulence, may be interpreted by the flight control computer to result from changes in camber settings. Similarly, camber adjustments may couple into and adversely affect other cruise mode performance, e.g., altitude hold or Mach hold. Possibly, by interating the camber changes at a sufficiently

slow rate, mode cross-coupling effects would be reduced to an acceptable minimum at the expense of dynamic response.

Optimum camber selection is a multivariable control problem and may require use of modern control techniques for satisfactory performance. Modern control design techniques are well-suited for the development of an active MAW control system for two reasons. First, multivariable synthesis techniques offer a systematic method for optimizing control law structures for multiple control requirements (e.g., drag minimization and maneuver load alleviation for maneuvering flight) where a number of sensor signals and control surfaces are available for the control law. Second, estimation techniques would be used to generate the required signals for the multivariable control law. For example, estimation filters could be used to define angle-of-attack, lift coefficient, drag coefficient, or some other parameter which represents a flight performance figure of merit. The design consideration for the estimation filters is that they must be capable of real-time implementation (which requires minimizing the software computational burden) and that their performance must not be degraded by maneuvering flight or by sensor system noise.

Prior to the initiation of the program described in this report, the available technical data base was inadequate to support a multivariable control design implementation within the AFTI/F-111 MAW development program schedule. In response to this deficiency, the Flight Control Division of the Flight Dynamics Laboratory formulated an exploratory study to develop the modern control design technology for aircraft applications. Objectives of this technology development study are listed as follows:

- Evaluate the application of modern control design techniques to the synthesis of complex aircraft control laws.
- Define multifunctional/multivariable control law structures which are adapted to advanced aircraft mission requirements.
- Assess the design impact of multivariable/multifunctional control systems.

2.5.2.2 Work Accomplished

A summary of the work accomplished in this task is given below:

(1) Developed the design objectives and requirements for the flight control system of an aircraft that integrates smooth wing camber control with conventional aircraft controls.
(2) Developed a conceptual design of a multivariable/ multimode flight control system.
(3) Developed an overview of multivariable design techniques and a detailed description of linear quadratic synthesis methods.
(4) Prepared a technology assessment of the proposed flight control system and recommendations for a research and development program that addresses these issues.

2.5.2.3 Conclusions

The study investigated the integrated design of a multivariable-multifunctional control system based on the application of modern control design techniques. An example of the need for such integrated design methods is an aircraft that combines wing shape control (which is mechanized to continuously control the leading and trailing edge deflections) with conventional aircraft controls (i.e., stabilon, throttle, rudder) for enhanced aircraft performance and handling qualities. This type of control system requires integration of aircraft stabilization, configuration management and structural load control functions that can benefit the operational performance of the aircraft for takeoff, climb, cruise, combat, and landings modes of flight. The actual mix between control functional requirements and modes of flight varies with aircraft type (i.e., penetration bomber,

large transport, cruise missile carrier or fighter).

Modern control design techniques are well suited for the development of complex control systems such as the MAW, for two reasons. First, multivariable synthesis techniques offer a systematic method for optimizing control law structures for multiple control requirements (e.g., drag minimization, lateral control, and maneuver load alleviation for maneuvering flight) where a number of sensor signals and control surfaces are available for the control law. Second, estimation techniques would be used to generate flight condition and camber corrections for optimizing the aircraft performance and the required signals for the multivariable control law. For example, estimation filters could be used to define wing tip deflection for a maneuver load control law.

Specific design features of the designed MAW multivariable multimode flight control system are summarized as follows:

- Single Control Structure
  - -Commanded Δn_Z, Q, α, γ or θ, V, h, P are kinematically consistent
  - -Mode selection is based on mode logic for α, θ, γ, V, and h
- Forward path control generator for all controls (δf, $\delta 1_H$, δ_R)
  - -Control commands are aerodynamically consistent with flight variable commands
  - -Integral error regulator terms are only needed for modeling errors, not for trim
- Multi-Command Control select
  - -All commands pass to servo when servo isn't saturated
  - -Commands are dynamically limited on a prioritized basis when servo is saturated

A comparison of control system design philosophies for multivariable-multimode MAW with the AFTI-16, AFTI-111 and the F-18 is

presented in Table 2.5-3.

The described control structure for a MAW optimal performance seeking flight control system offers great potential for making improvements in the control of an aircraft for performance, handling qualities, and structural load reduction. It provides a solution to the design goals formulated at the outset of this discussion. By virtue of this being a new and different aircraft flight control system structure, there are a number of technology/design issues that must be resolved in order to qualify the benefits of this approach. These are listed below.

(1) How accurate must the aerodynamic models which are used for the optimal path generator and the maneuver command generator be? The issues are modeling complexity, accuracy of the wind tunnel predictions, and the impact of the regulator and the on-line performance estimator for compensating for potential modeling errors.

(2) How identifiable are the flap and flight condition corrections for the on-line performance optmization? The issues are quality of the fuel flow measurements for multiple engines, a requirement for modeling engine and aircraft transients, and the magnitude of flight variable perturbations which are required to generate statistically significant identification results. In addition, would these perturbations be acceptable to the pilot?

(3) How accurate is the wing root bending estimation algorithm and what is its performance in maneuvering flight?

(4) What are the design problems associated with implementing the multivariable optimal regulator for the aircraft mission? The issues are regulator design items such as selection of weighting factors, cost function implementation,

Table 2.5-3 Comparison of Control System Design Philosophies

AIRCRAFT APPLICATION	CONTROL MODE IMPLEMENTATION	FORWARD PATH COMMAND GENERATOR	FORWARD PATH CONTROL GENERATOR	REGULATOR FEEDBACK	MULTI-COMMAND CONTROL SELECT
M^3(MULTIVARIABLE-MULTIMODE-MAW)	SINGLE STRUCTURE FOR ALL MODES	YES $\begin{pmatrix} n_z, Q, \alpha, \gamma, \theta \\ V, h \end{pmatrix}$	YES $(\delta_f, \delta_{l_M}, \delta_R)$	YES (MODEL FOLLOWING)	(DYNAMIC LIMIT & ESTABLISHED PRIORITY)
AFTI-16	SEPARATE STRUCTURE FOR EACH MODE	NO	NO	YES MODEL FOLLOWING $+\int$ ERROR	YES
F-18	SEPARATE STRUCTURE	NO	NO	NO	YES (HORIZONTAL TAIL)
AFTI-111	SEPARATE STRUCTURE FOR EACH MODE	NO	(L/D) MAX CAMBER FLAP	NO	NOT KNOWN

the impact of modeling uncertainty, methods for reducing the complexity of the gain matrix, and potential requirements for implementing nonlinearities.

2.5.2.4 Recommendations

All of the technical/design issues just described can be addressed with a study based on a limited scope (non-piloted and piloted) simulation. The simulation could be based on the AFTI/F-111 aircraft with the nonlinear aerodynamic model defined for one wing sweep position, a range in Mach number of $.2 < M < .9$, and be functionally dependent on angle-of-attack and altitude. This range in Mach number would allow investigation of landing approach, maximum endurance and maximum range flight test conditions. The engine model requirements include accurate representation of fuel flow, transient response, and performance dependence on ambient atmospheric conditions. A peripheral model (i.e., one that does not contribute to the dynamic degrees of freedom) of wing root bending is also required. To aid the design of the regulator, the nonlinear simulation must have the capability to generate a linear state model at a trimmed operating point.

An outline for a study plan based on the MAW simulation and structured to provide answers to the posed technology/design issues is shown in Figure 2.5-4.

2.5.3 <u>FIREBOLT Target Drone Analysis, Simulation and Flight Test Support</u>

2.5.3.1 Background and Goals

The FIREBOLT is a hybrid rocket-powered, high-altitude, supersonic, recoverable target. The FIREBOLT is air-launched from an F-4 aircraft and is capable of climbing from launch altitude to any preset altitude up to 10,000 feet with speeds from approximately Mach 0.9 to

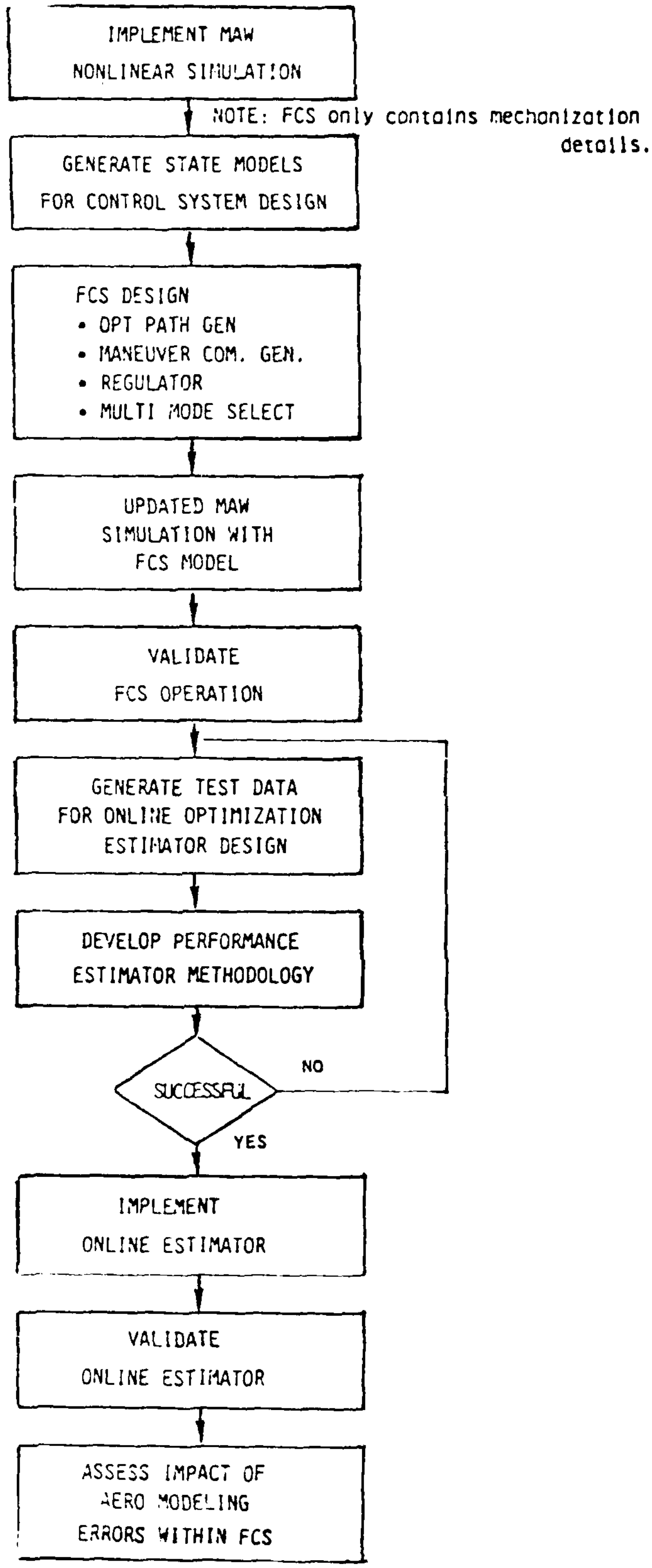


Figure 2.5-4 Study Plan Outline

Mach 4.0. The FIREBOLT is designed to respond to ground initiation and automatic initiation of preprogrammed maneuvers. The vehicle control system is also designed to maintain ±.1 Mach number variation of a preset speed during these maneuvers. The FIREBOLT will perform high "g" (1.1 to 5) lateral turns, high "g" (±5.0) vertical maneuvers, S-turns, Mach number increases/decreases, and ±5000 foot altitude maneuvers. Because these maneuvers are typical evasive enemy tactics, they provide the user a more realistic target to train air crews or evaluate advanced missile weapon systems such as the AMRAAM.

The purpose of this task was to develop a simulation which provides the Eglin Air Force Base Armament Division an in-house, quick-reaction capability to evaluate the FIREBOLT performance and stability, independent of the prime FIREBOLT contractor's assessments, and provide a tool for the FIREBOLT flight test program.

The main objectives of this project were to:

(1) Develop, update, maintain and validate the six-degrees-of-freedom (6DOF) digital simulation. This included all design changes to the FIREBOLT vehicle made by TRA or the Air Force and included model updates based on post-flight test analysis. All updates were documented and provided to the Air Force. Validation of the simulation was accomplished by matching simulation performance characteristics to flight test results. The 6DOF simulation was written in FORTRAN IV and subsequently modified to FORTRAN V, and is compatible with the CDC 6600 at Eglin Air Force Base.

(2) Provide an independent assessment of the FIREBOLT flight control system design, including design changes and modifications. Also provide written and oral comments on FIREBOLT contract data items in the areas of:
- Flight control system
- Aerodynamics
- Test plans, reports, and analysis.

(3) Provide pre- and post-flight test analyses on each flight

test vehicle to include, but not be limited to, flight performance, profile, sensitivity analysis, diagnostic analysis of problems and recommendations.

(4) Provide operational instructions to Air Force personnel in the use of the 6 DOF simulation.

2.5.3.2 Work Accomplished

All the objectives of the task were completed. An overview of the digital simulation is presented below.

The current FIREBOLT target model simulates the motion of a rigid body through the atmosphere in three-dimensional space with respect to a flat non-rotating earth.

The model is based on physical modularity in which parts of the program called modules functionally represent subsystems of the missile or its external environment. The order of processing the modules is shown in Figure 2.5-5, which is generally clockwise beginning with the airframe and external environmental modules, proceeding through the sensor modules, and finally to the steering and control modules. There are five functional groups of modules in the program identified by the letter G (geophysical), S (sensor), C (computers), A (airframe), and D (dynamics). The names and functions of the modules are as follows.

<u>FIREBOLT Simulation Modules and their Functions</u>

G2: Wind and Gust Module:	Computes wind components, air density, and speed of sound from measured atmospheric conditions. Used to simulate a specific test flight.
G3: Air Data Module:	Computes wind components and atmospheric data from a standard atmosphere model.
G5: Coordinate Conversion Module:	Computes Euler angles and trans-

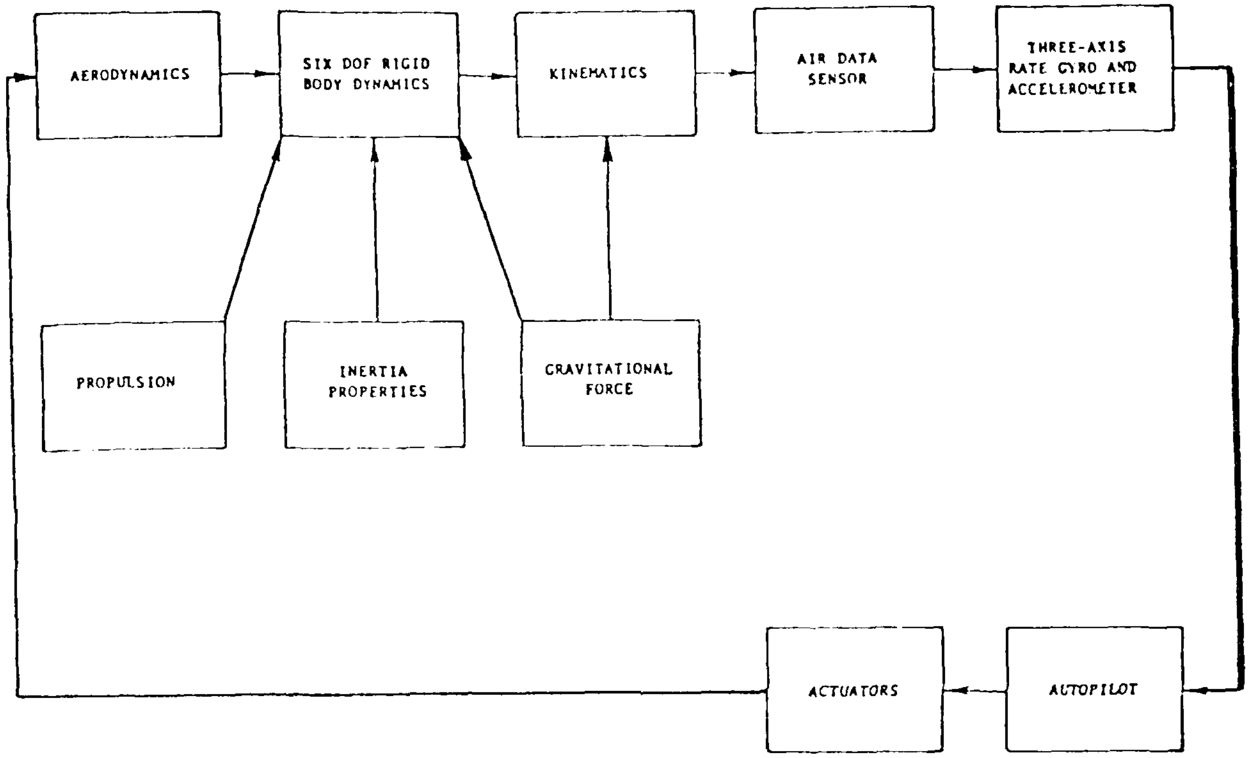


Figure 2.5-5 FIREBOLT Major Subsystems for 6 DOF Simulation

	formations between the earth-fixed and the body-fixed coordinate systems. Also computes angle of attack and sideslip.
C1: Autopilot Module:	Includes navigation functions and vehicle stabilization computations using sensor data and input parameters. Outputs of this module are the control deflection commands.
C4: Actuator Module:	Computes the dynamics for the actuators' control surfaces.
A1: Aerodynamic Coefficients:	Interpolates for aerodynamic coefficients as a function of Mach number, angles of attack, and control defelctions. Computes the total forces and moment of aerodynamic coefficients.
A2: Aero Force and Moment Module:	Computes the aerodynamic forces and moments acting on the vehicle.
A3: Propulsion Module/Mass Properties:	Computes control signals to the propulsion unit. Contains a model of the propulsion system and the mass properties variations due to fuel burned.
D1: Translational Dynamics:	Computes vehicle accelerations due to aerodynamic and propulsion forces. Transforms acceleration to the earth-fixed

coordinate system, adds gravitation, and integrates to compute velocity and position.

D2: Rotational Dynamics Module: Evaluates total moment (including thrust misalignment) acting on the vehicle and computes the rotational dynamics of the airframe. Also updates direction cosines from updated body rates.

A brief description of each module is given in Table 2.5-4. The modules are interconnected by COMMON storage location called C(3510). The module interconnection diagram is shown in Figure 2.5-6. This diagram shows the principle variables going from one module to another.

This simulation was developed on the Eglin CDC CYBER computing system. Several unique capabilites have been built into the FIREBOLT software. It has the ability to recall every subscripted numerical value used in the program during the first few integration steps for debugging purposes. It can produce 4020 film plots of fifteen variables versus time for each executed trajectory, or plot two variables against each other with the remaining thirteen variables versus time. It also has the ability to display the variables and their numerical location in common storage in alphabetical and numerical order. This unique feature of the model is a powerful debug device which reveals available storage locations for new variables, identifies those presently being used, and flags variables that occupy the same memory location but have different variable names and the percentage of unused common storage. Finally, it can produce numerical results for each integration step (or larger time increment) for sixty output variables per computer run. Any variable selected should be in the C(3510) array.

Table 2.5-4 Definitions of Frequently Used Variables

Variables or Constants Associated with Modules

Module	Variable	Units	Definition
G2	W_{TX}, W_{TY}, W_{TZ}	ft/sec	Components of wind, including gusts
G3	q_d	lb/ft^2	Dynamic pressure $(1/2\rho\ V_a^2)$
	M	(non-dim)	Mach number
	α,β	degrees	Angles of attack and sideslip
	V_{AT}	ft/sec	Missile velocity with respect to air
G5	ψ,θ,ϕ	degrees	Euler angles, yaw, pitch, roll, from tangent plane to missile body axes
	R_s	feet	Slant range from missile to origin of tangent plane
	V	ft/sec	Magnitude of missile velocity
C1	δ_{CC}, δ_{AC}	degrees	Control surface deflection commands from navigation and stabilization autopilot loop
C4	δ_C, δ_A	degrees	Control surface deflections causing moments about missile axes (e.g., aileron, canards)
A1	$C_A, C_Y \cdot C_N$ C_ℓ, C_m, C_n	(non-dim) (non-dim)	Aerodynamic coefficients, body axes
A2	S		Reference area
	$\bar{C}$		Reference length
	F_X, F_Y, F_Z	ft-lb	Components of aerodynamic force along wind (AA) or body (BA) axes
	L,M,N	ft-lb	Components of aerodynamic moment along body axes
A3	T_X, T_Y, T_Z	lb	Components of thrust force along wind (AA) or body (BA) axes
	L_T, M_T, N_T	ft-lb	Components of thrust moment along wind (AA) or body (BA) axes

Table 2.5-4 Definitions of Frequently Used Variables (Cont'd.)

Module	Variable	Units	Definition
D1	$A_{XBA}, A_{YBA}, A_{ZBA}$	ft/sec^2	Total thrust acceleration due to engine
	V_X, V_Y, V_Z	ft/sec	Components of velocity, tangent plane axes
	X,Y,Z	feet	Components of position, tangent plane axes
D2	I_{XX}, I_{YY}, I_{ZZ}	$slug\text{-}ft^2$	Principal moments of inertia, or X,Y,Z axis moments of inertia
	I_{XZ}	$slug\text{-}ft^2$	XZ product of inertia (stability axes)
	P,Q,R	deg/sec	Components of missile angular rate about body axes
	a_{ij}	(non-dim)	Elements of direction cosine matrix from earth-fixed tangent plane axes to body axes

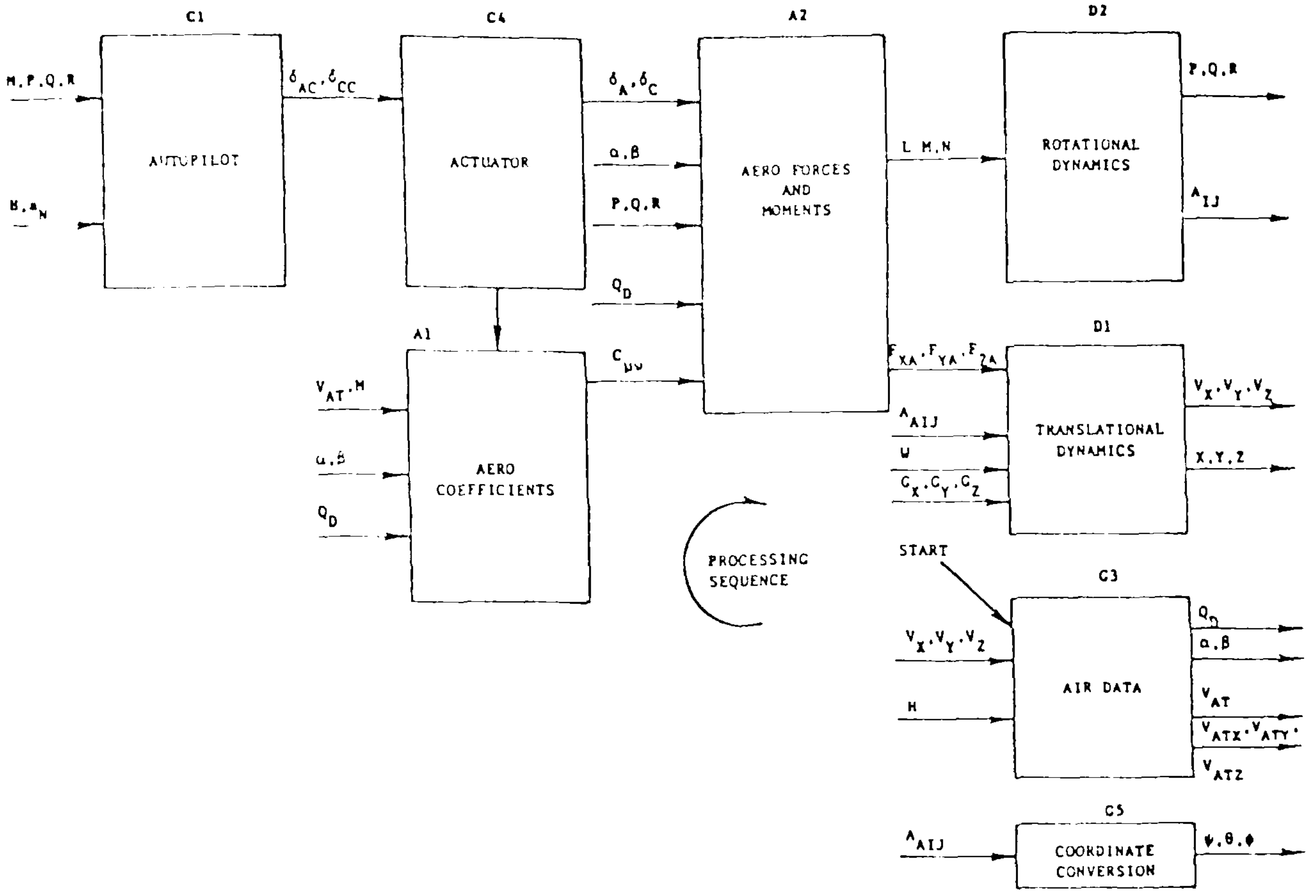


Figure 2.5-6 Module Interconnection Diagram for FOREBOLT Simulation

2.6 CONTROL/DISPLAY DEVELOPMENT SUPPORT

Systems Control Technology, Inc., is supporting the Crew Systems Integration Branch of the Air Force Wright Aeronautics Laboratories (AFWAL/FIGR) in the development of control display technology. The digital synthesis simulator (DIGISYN) is used to investigate the impact of digital avionics information on pilot/aircraft performance and effectiveness.

DIGISYN consists of a fixed-base A-7 cockpit, a test operator's console (TOC), and a computer system. The fixed-base cockpit is outfitted with advanced controls and displays as follows: 1) head-up display (HUD), 2) veritcal situation display (VSD), 3) horizontal situation display (HSD), 4) multi-function keyboard (MFK), 5) multi-purpose display (MPD), 6) master mode panel (MMP), and 7) master function select (MFS) panel. The HUD, VSD, HSD, and MPD are displayed on Cathode Ray Tube (CRT) devices. The MFK is implemented by using either a CRT display with peripheral push button switches or by using an array of projection switches. The MMP and MFS are arrays of back-lighted pushbutton switches. The cockpit also includes traditional controls and displays as follows: 1) McFadden three-axis control loader, 2) throttle, 3) map cursor control, and 4) electro-mechanical analog instruments.

The TOC provides real-time test monitoring and control for a team of investigators. Each cockpit display is repeated on the TOC for monitoring, and an array of push-button control switches is provided for test sequencing.

The computer system provides a real-time simulation of the A-7 airframe, generates and drives the cockpit displays, scores pilot performance during threat, pop-up and MFK tasks, and records data for off-line statistical analyses. The central computer is a PDP-11/50 with 124K words of memory. The following peripherals complement the PDP-11/50: 1) color as well as black and white RAMTEK GX-100A graphic generators, 2) dual 1.2M word disk cartridge drives, 3) 9-track magnetic tape drive, 4) general purpose control and display (GPCD) system, 5) CRT console terminal, 6) card reader, 7) electrostatic

printer, 8) digital input/output (I/O) channel, and 9) analog I/O channel. A pictorial diagram of the DIGISYN is presented in Figure 2.6-1.

The DIGISYN facility is being used for investigation of cockpit displays, display formats, and cockpit communication methods. The support tasks included: (1) 2-D Display Software Support, (2) Color Terrain Display System, (3) Speech Applications Experimental Support, (4) Flat Panel Display, (5) Pictorial Emergency Procedures/Speech Interaction, and (6) Microprocessor Application of Graphics and Interface Communication.

2.6.1 2-D Display Software Support

A two-dimensional microwave landing system display format was developed by AFWAL/FIGR to examine the feasibility of integrating attitude, lateral performance, predicted lateral performance and situation information on a single display surface. The profile was a single scale graphic view of the path to be flown (see Figure 2.6.1-1). The entire profile rotated with aircraft heading changes so that current heading was always at the top of the display. In this way, drift was always shown the same as it would be seen in a real world, heads up manner. The flight path moved toward the bottom of the display surface and to the center of the aircraft symbol when on course, at a rate scaled to groundspeed. The need for this kind of display configuration became apparent when pilots experienced problems with position orientation and control on complex MLS approach trajectories. Systems Control Technology was responsible for developing a navigation math model and navigation-steering software required to present the format in real-time, interface software with existing DIGISYN software, and engineering analysis support in the modification of the existing aircraft model software to enable simulation experiments to take place.

<u>MLS Software</u> - The MLS software was written to compute a predicted aircraft position at selected times in the future. With the

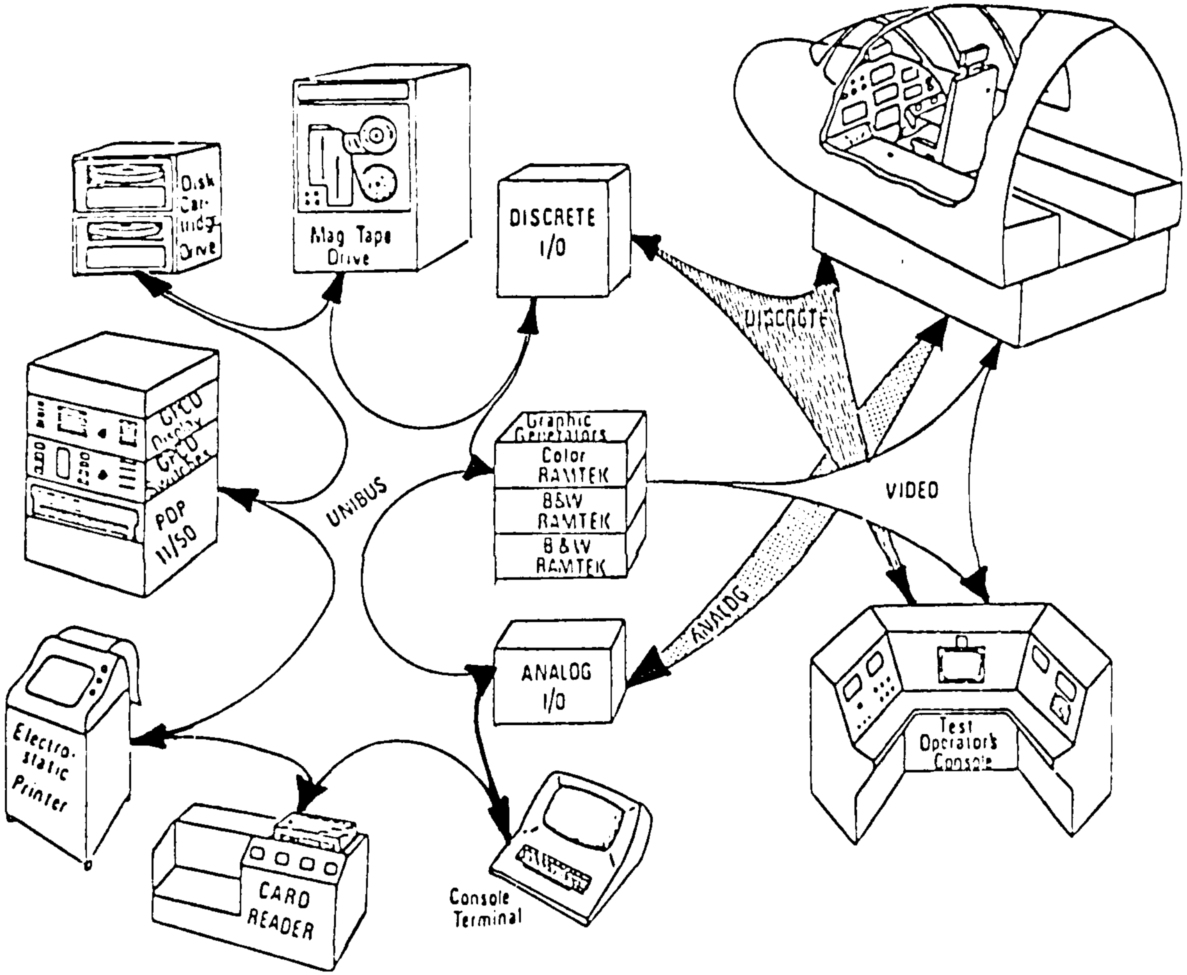
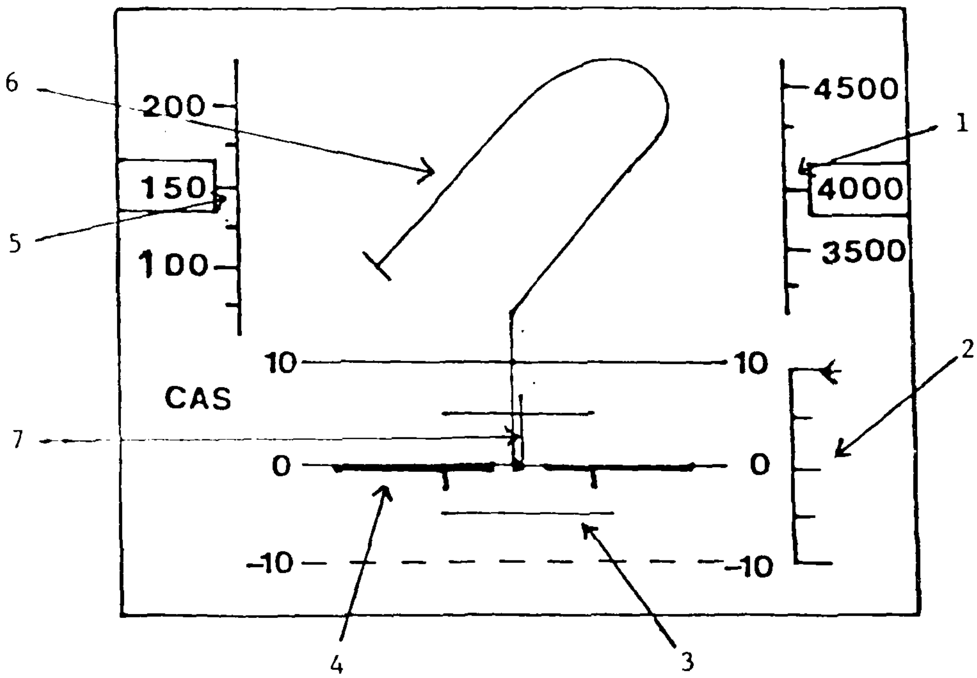


Figure 2.6-1 Pictorial Diagram of DIGISYN



1. Altitude scale
2. Glideslope scale
3. Pitch attitude scale
4. Aircraft symbol
5. Airspeed scale
6. Approach profile
7. Path predictor

Figure 2.6.1-1 Test Display

addition of a desired ground track display, the pilot was able to see ground track errors and judge for himself any corrective measures to be made to the aircraft flight path. Curved track legs between way-points were supported in order to accommodate realistic landing patterns. Software was also written to generate a pitch command to the pilot to allow for corrections in altitude error relative to a pre-defined set of waypoints. The most salient features of the MLS software are summarized as follows.

A. Path Prediction: The MLS software relieved airframe velocity information and generated predicted ground positions at times 5, 10, and 15 seconds relative to current position and time.

B. Curved Track Legs: The path between waypoints, formerly a mandatory straight line, allowed for a curved path. The only limitation on the curve was that it's radius had to be fixed.

C. Altitude Tracking: MLS commands provided climb and dive rate information to the pilot to allow easy tracking of a given reference altitude. Rate damping was included to allow smooth approaches to the command altitude.

D. Glide Slope Indicator: At the beginning of the seventh track leg, a glide slope error indicator was activated. Unlike a conventional conical patterned GSI error envelope, the MLS software generated an error corridor such that a given GSI deflection always translated to a constant error.

E. Fastest Possible Run-Time Execution: All of the complex calculations were performed in the initial condition mode, leaving only labeled variables and simple equations to be performed in the real-time run mode.

F. In order to simplify many calculations, all references to latitude and longitude were converted to feet. The beginning point of the mission was defined as (0,0).

DIGISYN Interface Software - In order for the MLS software to operate, data from the airframe model had to be sampled in real time. A memory partition named SYSCOM (System Common) was created to accomplish this needed interface. Three different areas of SYSCOM (VSD2D, BLOCKS and SWITCH) were created. All communication between the MLS software and airframe software was accomplished by passing parameters through the BLOCKS area. All communication between the MLS software and VSD display software was accomplished by passing parameters through both the VSD2D and BLOCKS areas. All communication between the MLS software and switch processing software was accomplished by passing data through the SWITCH area.

Two modules of the aircraft model were modified for the MLS simulation experiment. Subroutine EARTHF, a routine which integrates the ground position of the aircraft from the ground velocities, was modified to calculate all distances and positions in feet instead of radians. This allowed the MLS software to use feet as the unit of measure, saving computational time. The AERO/module which computes pitch, roll, yaw, lift and drag components from a linear aerodynamic model was modified to include a ramp function to introduce drag and lift from flaps and landing gear. This modification produced a more gradual and realistic effect than the effect produced by the original step function input. The ramp function was implemented with a period of 2.5 seconds.

The MLS software is documented in the Computer Program Product Specification for the Microwave Landing System (MLS) software, Simulation Technology Document Number STI-80-OPR-084, 29 December 1980.

2.6.2 Color Terrain Display System

In order to assist the fighter pilot of the future in performing

a mission, AFWAL/FIGR personnel examined the feasibility of using a color CRT to display a synthetic terrain format to the pilot. This format provides a computer generated version of the real world and can be generated by digitizing terrain and cultural features and storing them in an on-board computer. The data can then be correlated with the aircraft's inertial navigation system during flight and presented to the pilot on a head-down E-O display device.

The feasibility of using computer image generation techniques to display terrain and cultural features was demonstrated under a previous Synthetic Terrain effort. The DIGISYN was used as the test-bed for performing the effort. The effort yielded a Synthetic Terrain Display Format that could be updated in approximately 3-5 seconds, not close to a real-time update. The slow update rate appeared to be caused by the DIGISYN PDP-11/50 computer system and the RAMTEK graphics generators.

The Synthetic Terrain Expanded Capability Analysis was concerned with definitizing the reasons for the non-real-time update of the terrain format and specifying how they could be overcome. This involved not only examining the DIGISYN hardware and software, but examining both computer and graphics hardware that could be added to generate a real-time synthetic terrain display format, and that could be expanded to generate other complex display formats. The solutions examined included modifying the algorithm for the terrain calculation and display, as well as the connection of additional computer and graphics hardware. In order to meet the objectives of this effort, a number of specific tasks were undertaken. They are described in the following sections.

Requirements Definition - In defining the requirements of the display system, certain limits were placed on both the scenario and aircraft performance. The proposed scenario consisted of a straight-in leg to the target, a pop-up maneuver, a 45 degree dive to the target, weapon delivery, and then continuation onto another "straight and level" leg of the mission. Aircraft performance limits were placed at 100-5000 feet of altitude, 600 knots calibrated

airspeed, $\pm$ 45 degrees of flight path angle, $\pm$ 60 degrees of bank and $\pm$ 26 degrees horizontal 134 $\pm$ 13.5 degrees vertical field of view. With these bounds, a 10 minute demonstration covering 100 miles of terrain data base was defined. Terrain features such as mountains and trees and cultural features such as railroad tracks, bridges, roads, rivers, lakes, city outlines, airports, warehouses, trains, tall buildings and transmission lines were identified as features that must be displayed and easily recognizable.

Requirements were also defined for the display itself. It was determined that a 5 or 7 inch diagonal color display with a 512 x 512 resolution and fine pitch (spacing between adjacent color triads) in the case of a 3-gun tube of no more than 0.31mm was required for this task. The complexity of the format necessitated an update rate of at least 5 times a second while displaying more than 5 colors at one time.

Analysis of Current DIGISYN Capability - The generation of the terrain display using the DIGISYN facility required approximately 3-5 seconds to complete. This was far below the 0.2 seconds required in order to display the scene at 5 times per second. A number of inhibiting factors were found.

The central processor unit of the DIGISYN facility was a PDP 11/45 processor with 64k words of core memory and 32k words of MDS memory. While this computer served the laboratory well in driving the airframe as well as head-up and other display software, the added computational requirements of the terrain display were beyond the processing capabilites of the computer.

Another limiting factor of the DIGISYN system was the graphic display capability. In order to display one frame of the synthetic terrain format, approximately 17,770 words of information had to be processed by the RAMTEK LX-100A symbol generator. This required approximately 1.327 seconds of display time per frame using a canned scenario stored on magnetic tape. It was determined that increased computational power coupled with a new display processor could help overcome some of the display limitations.

Terrain Generation Analysis - Because of the large amount of computer resources required to generate the synthetic terrain format, a survey of available databases and computation techniques was performed to determine how the creation of terrain features could be modified to facilitate a real-time update rate. A database received from the Avionics Laboratory (AFWAL/AAAT) was ultimately utilized. This database covered approximately 60x40 nautical miles of Defense Mapping Agency (DMA) level 1 data. The database contained terrain features, but no cultural ones (i.e., no railroads or bridges).

The software used to access this database and generate the terrain features was largely based upon the Terrain Map Simulation (TMS) software received from AFWAL/AAAT. This software was rehosted on the DIGISYN system to perform initializations, navigate the aircraft, and generate the perspective veiw of the terrain.

Using existing equations, it was found that 1.3 seconds of computation time on the PDP 11/45 was required to calculate terrain altitude for the nominal 30,720 data points needed to yield sufficient terrain detail. A potential solution to reducing this computation time required the use of an interpolation technique. The use of a hardware polynominal computation processor was also considered as a possible solution to this problem. Given the definition of these limitations, a number of hardware vendors were contacted in order to determine if a higher data transfer rate, faster computational speed, and greater amounts of main memory and mass storage were viable solutions to the terrain generation update problems.

Display Generation Analysis - In addition to the terrain features analysis, an analysis of graphics display requirements was also performed. This task included an investigation of various display techniques which could be employed to generate terrain and cultural features more expeditiously than the current implementation of the format. A survey of display hardware and software currently available was conducted in order to identify systems capable of attaining the update rate, color, and resolution requirements of the format.

Upgraded System Configuration Analysis - The results of the DIGISYN limitations analysis, the terrain generation analysis and the graphics display analysis were combined with new timing and cost information to identify candidate system configurations which would not only meet the earlier defined requirements, but would do so with the least impact to the current DIGISYN configuration and in the most cost effective manner. To achieve this goal, the following tasks were performed.

A. Information gathered on available host and graphics processors was analyzed.

B. Benchmarks were run on candidate host and graphics processors.

C. The availability of interfaces between systems was identified.

D. Training and maintenance costs were defined.

E. Software conversion costs were estimated.

F. DIGISYN adaptability was examined.

Recommendations - The results of the color terrain display system analysis revealed problems in both the computational power and graphic display capability of the DIGISYN system in generating the terrain display. The survey of the host processors and graphics processors identified configurations with attributes to alleviate these problems (see Tables 2.6.2-1 and 2.6.2-2). The following recommendations were made to alleviate the update problems.

1. Acquisition of a new host processor. The VAX 11/780 was recommended as the host processor for its benchmark speed, versatility, ease of software rehosting, compatibality with current DIGISYN configuration, available mass storage and price.

Table 2.6.2-1 Candidate Host Processor Attributes

VENDOR	SYSTEM	WORD SIZE (BITS)	VIRTUAL MEMORY	CACHE MEMORY	BUS TRANSFER RATE (MB/SEC)	CPU CYCLE TIME (NSEC)	MASS STORAGE (MB)	ARRAY PROCESSOR INTERFACE	GRAPHICS PROCESSOR INTERFACE	GRAPHICS PROCESSOR DRIVERS	BENCHMARK SPEED (SEC)	PRICE ($1000)
Data General	S/250	16	No	N/A	2.5	500	50+	Integral Processor	All	IK, MG	5.0	130
	MV8000	32	Yes	Yes	2.3	880	96+	N/A	All	IK, MG	3.38	185
DEC	VAX 11/750	32	Yes	Yes	2	400	7-256	CSPI, FPS	All	All	10.26	175
	VAX 11/780	32	Yes	Yes	6.6	280	67-256	CSPI, FPS	All	All	2.56	230
Harris	H500	48	Yes	Yes	2.5	290	40+	N/A	RM, SA	–	4.022	172
	H800	48	Yes	Yes	2.5	270	40+	N/A	RM, SA	–	2.514	245
Perkin-Elmer	3242	32	No	Yes	1.2	500	67-256	CSPI, FPS	RM, SA	SA, MG	3.86	208.7
Prime	550 Mod II	32	Yes	Yes	2.5	750/540	40-300	CSPI, FPS	RM, MG	RM	8.24	142
	750	32	Yes	Yes	8	750/540	40-300	CSPI, FPS	RM, MG	RM	4.39	191
SEL	3277	32	No	N/A	3.2	600	80-300	CSPI, FPS	All	MG	5.15	–
	3277/80	32	No	N/A	3.2	600	80-300	CSPI, FPS	All	MG	2.91	191
	32/87	32	No	Yes	3.2	600	80-300	CSPI, FPS	All	MG	2.52	350

Table 2.6.2-2 Candidate Graphics Processor Attributes

VENDOR	SYSTEM	SIMULTANEOUS COLORS	LOCAL STORAGE	INTERFACE RATE	RESOLUTION	POLYGON FILL	3-D TRANSLATE(T) ROTATE(R) CLIPPING(C) PERSPECTIVE(P)	CYCLE TIME MAIN PROCESSOR	SPECIAL FEATURES	BENCHMARK SPEED (SEC)		COST ($1000)
IKONAS	RDS-3000	16	128 KB RAM 8 KB Image Processor	2 MB/SEC Host 10 MB/SEC Video	512^2 Or 1024^2	Yes	T R C P	200 NSEC	H/W Divide Switchable Scan Rates	.001 .006	.003 .012	60
MEGATEK	Whizzard 7250	16	196 KB RAM	1.5 MB/SEC	512^2	Yes	T R C	160 NSEC	Virtual Addressing Pan/Zoom	N/A	N/A	60
RAMTEK	RM-9400	64	128 KB RAM [illegible] KB ROM	1.5 MB/SEC	640 x 480	Yes	No	284 NSEC	Declutter 255 KB Volatile Memory	Slow	Slow	80
SANDERS	Graphic 8	16	256 KB RAM	1 MB/SEC	512^2 640 x 480	Yes	T R C P	115 NSEC	Split Screen(3) Zoom With Perspective	.050	.066	60

2. Acquisition of a new graphics processor. The Sanders Graphic 8 was recommended because of its speed, polygon fill, 3-D hardware, 16 simultaneous colors and local storage.

3. Update of terrain creation algorithm. Modification of the terrain creation algorithm was recommended in order to take full advantage of the new processor and graphic capabilities.

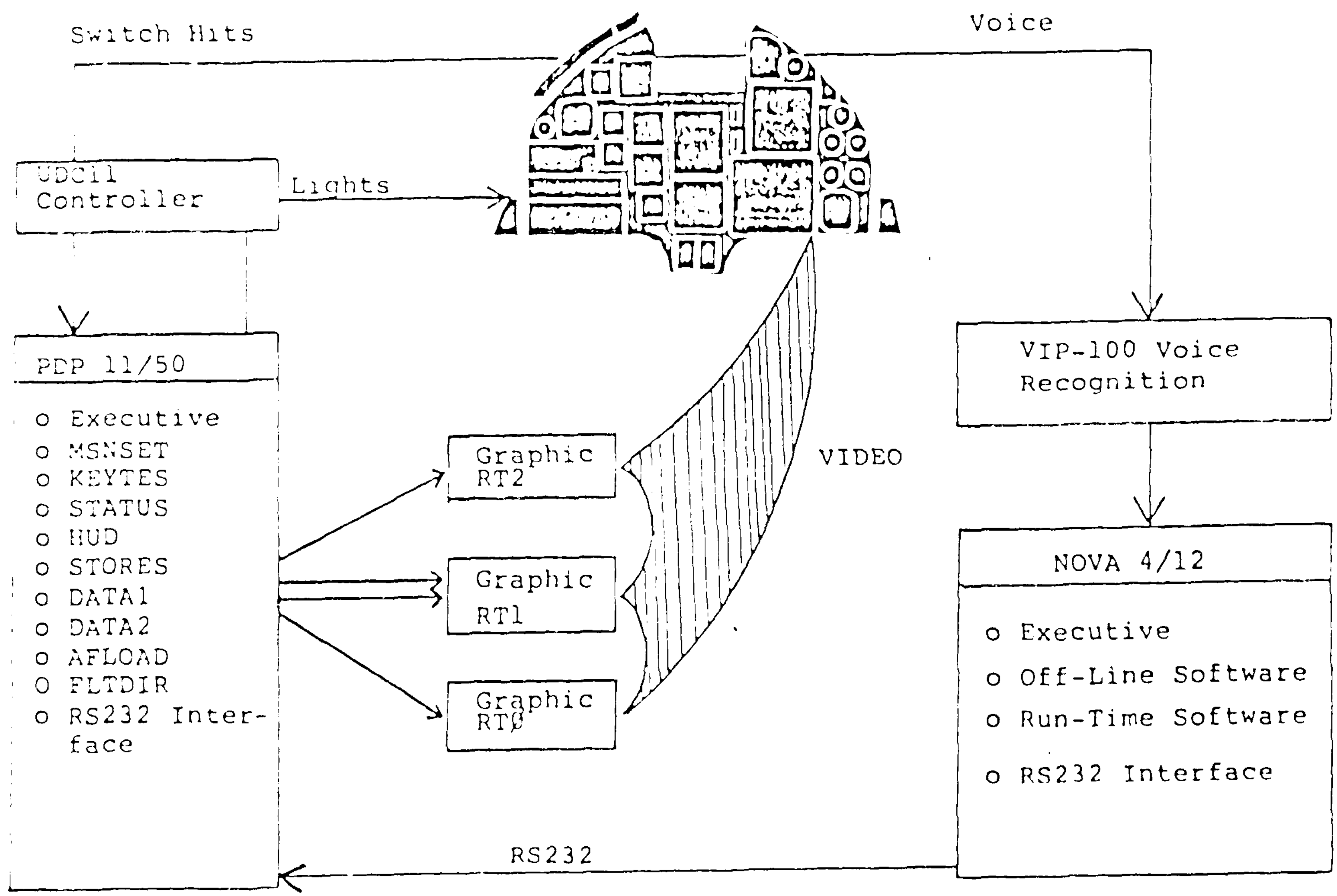
4. Acquisition of an array processor. The purchase of an array processor for the new DIGISYN system would only be necessary if the required 5 times per second display update rate could not be met by following the first 3 recommendations. A floating point systems array processor was the recommended choice because of its high order language compiler and compatibality with the VAX 11/780.

2.6.3 Speech Applications (SPAM) Experiment Support

Systems Control Technology provided systems integration support needed to tie an ASTEC speech recognition system into the DIGISYN facility and support an FIGR experiment designed to investigate the voice activation and control of aircraft displays. A functional overview of the SPAM simulation setup is shown in Figure 2.6.3-1. To perform this integration process and provide study support, the following specific tasks were performed.

PDP 11/50 System Generation - A new RSX11-M Version 3.1 operating system was generated for the DIGISYN facility in order to make an existing DL11-E RS232C interface port available to both the operating system and user software. This interface was used for communication between the DIGISYN PDP 11/50 computer and the Data General Nova Computer System which served as host to the ASTEC speech recognition system.

Figure 2.6.3-1 SPAM Cockpit Simulator



Nova/PDP 11/50 RS232 Interface - The Nova and PDP computers were linked via an RS232 communications line. SCT developed an interface protocol which permitted one-way communication from the Nova computer to the PDP. The information passed to the PDP computer consisted of integers which represented words or phrases recognized by the ASTEC recognition system. An interface handler developed by SCT processed these inputs and distributed them to various existing DIGISYN software routines for further processing.

ASTEC User Demonstration Software - SCT developed, tested and documented a user software demonstration package which made use of run-time software delivered with the Nova computer system. This software demonstrated the capabilities of the ASTEC system by sending codes to the PDP 11/50 computer system which represented keyboard switch hit information. Through the use of this package, a pilot could now control the multifunction control display by voice input.

Modification of Existing DIGISYN Software - The modification of existing DIGISYN software primarily consisted of general code cleanup for better readability and faster computational speed. Some major changes were made however to both the keyboard (KEYTES) and stores status (STORES) displays. While the capability to change the keyboard information by voice command was the primary interest of the experimental effort, a parallel requirement of the effort was the generation of a communication link between the keyboard and stores status displays. This communication link enabled the pilot to receive immediate pictorial feedback of any weapon option changes made on the multifunction keyboard display. Also, the routine which defined the weapon load for the stores status display was completely rewritten. Previously, the stores status display could only reflect a weapon load that was predefined and stored as data in a data file. The new routine was written to query the system common area of memory for weapon load information every time this data was updated by the keyboard software. The resulting effort was an immediate stores status display update for every weapon option change made by the pilot.

Changes made to other existing DIGISYN software included the modification of the data scoring and data reduction routines, changes to the keyboard switch counting and scoring routine, and minor modifications to the mission setup, general purpose control and display switch processing and system common memory tasks.

With the completion of the software modifications, the entire simulation software package was assembled and integrated. Modifications were made in both the overall timing of the simulation software and the amount of memory allocated to the operating system. With the increased input and output demands made by the simulation software, it was determined that more memory was needed for operating system storage. The system was modified to provide the operating system with an ample input/output memory pool.

Experiment Support - During the course of the experiment, SCT provided programming support and experiment operator support as required. The support encompassed "quick-fix" software changes, station operation support, and systems engineering support in experimental set-up and data reduction. During the analysis of the experimental data, it was determined that the time lag between voice recognition and actual display change must be measured. SCT developed an approach to measuring this lag and generated a computer program for the actual measurements. Multiple time lag measurements were made under all experimental conditions and the results were reported to FICR.

2.6.4 Flat Panel Display

The United States Air Force and the Canadian Government of Industry Trade and Commerce has a memorandum of agreement which supports the joint development, fabrication, test and evaluation of a Flat Panel Light Emitting Diode (LED) Multi-Mode Matrix (MMM) display (see Figure 2.6.4-1). The development of this technology would test the possibility of using a multipurpose display of this type on instrument panels in aircraft cockpits for the presentation of real-time flight

Figure 2.6.4-1 Multimode Matrix (MMM) LED Display

parameter and system status information. In support of the evaluation of this device, SCT participated in conducting a ground based aircraft simulation using the MMM display.

The DIGISYN facility in AFWAL/FIG was used for the simulation experiment. In conducting this study, a new set of simulation software was written to interface the MMM display system to the DIGISYN PDP 11/50 computer system and to interface the PDP 11/50 to a PDP 11/55 computer system (see Figure 2.6.4-2). The simulation also required the use of existing DIGISYN software, which was modified accordingly. The following sections describe both the generation of the new software and modification of the existing software.

MMM Software - The new software generated for the MMM experiment effort was divided into four parts. They were 1) the MMM simulation executive control programs, 2) the MMM interface control program, 3) the MMM formatter program and 4) the DA11BJ transfer software program. Each of these is described in the following sections.

- MMM Simulation Executive Control Programs - To accomplish all of the tasks required of the MMM simulation software, a decision was made to utilize two PDP 11 processors. The DIGISYN PDP 11/50 served as the master executive processor and a PDP 11/55 located in the Crew Station Integration Laboratory served as the slave executive processor. Two separate computer programs were written to serve as executive control routines for the interface of the two computer systems. The responsibility of each computer program was to provide a communication link between its own computer system's common area of memory and a DA11B-J hardware interface connecting the two computers. Additional responsibilities of the master executive program included the control of all analog-to-digital input, digital-to-analog output, MMM formatter software, MMM interface control software and scheduling of the data recording software. The primary task of the slave executive program was to schedule and control the aeromodel software.

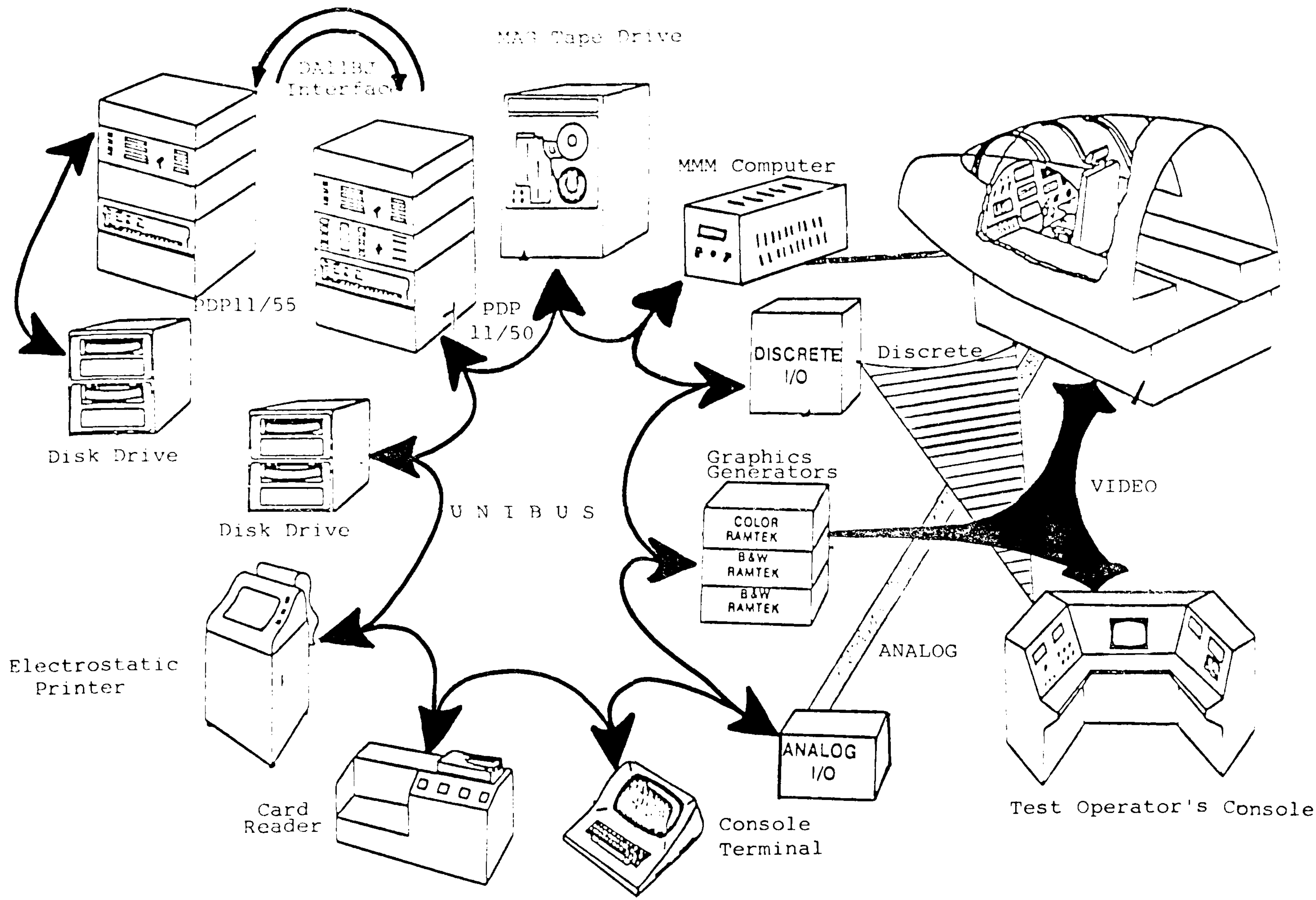


Figure 2.6.4-2 Flat-Panel Display Configuration

• MMM Interface Control Program - A total of 13 different software routines were written to perform the input and output control between the DIGISYN PDP 11/50 computer and the MMM computer. Of these 13 routines, one served as the executive program that scheduled 2 routines for initialization, 3 routines to send and receive data messages to and from the MMM computer, and 7 routines to identify errors and take appropriate error action. All transfers of data were accomplished using a DR11-B Direct Memory Access (DMA) hardware interface. The communication protocal for all input and output was defined in the MMM Interface Protocal Document supplied by the manufacturer of the MMM Display and computer.

• MMM Formatter Program - A total of 9 software routines were written to perform the formatting of displays for the MMM computer. These displays include an engine status indicator, an electronic attitude direction indicator, an electronic horizontal situation display, a navigation indicator, and a precision approach indicator. Of these 5 different formats, only one, the electronic attitude direction indicator, was used during the evaluation of the MMM display. In addition to the 5 routines which actually formatted the displays, one routine was written to serve as an executive controller and scheduler, one routine was written for the initialization of all display flags and scale factors, another performed a checksum of the entire output data buffer, and a fourth was written to allow the MMM computer to generate a given unspecified format of an experimental or trial nature.

Each of the 9 routines was written in FORTRAN and was designed to run on the DIGISYN PDP 11/50 computer. Each of the formatting routines generated an integer buffer of data for the MMM that was fully responsive to the interface control software.

• DA11B-J Transfer Software - Two programs were written to control the transfer of data through the DA11B-J hardware that connected the PDP 11/50 and PDP 11/55 computers. The master transfer software resided on the PDP 11/50 and was used by the master executive control routine to initiate the transfer of data to the slave PDP 11/55 computer at a 50 Hertz rate. Upon reception of data from the master processor, the slave transfer software residing on the PDP 11/55 was used to initiate a response transfer of data back to the master computer. Both of these programs were written in the PDP 11 assembly (MACRO) language and were designed to execute under the RSX-11M V3.1 operating system. Both programs were directly controllable only from the executive control programs of each computer system.

<u>Modification of Existing DIGISYN Software</u> - In order to carry out the simulation testing of the MMM display, various existing programs residing on the DIGISYN computer system had to be utilized. It was necessary, though, to modify these programs to meet the specific requirements of the software effort.

The mission setup software was changed to reflect the new experimental matrix. Other changes involved the initialization of various flags for MMM control and the repositioning of the aircraft to an initial condition of 10000 feet altitude, 300 kts airspeed and 0 degrees heading.

The data recording software was extensively modified for the MMM simulation effort. Under typical simulation studies run on the DIGISYN facility, the data recording software handled the collection of flight performance data during both a pre-event and event phase. This software also normally contained some logic used for the collection of keyboard switch information. To attain greater computational speed, much of the code pertaining to these capabilities was deleted, since neither were required in this simulation. Some logic was added though for the complete control of the data recording process by the master executive control program.

The status display provides the experimenters with feedback per-

taining to the current state of the mission, software and pilot activities. The status display software for the MMM experiment was completely rewritten to provide the experimenters with information concerning matrix number, pilot number, treatment number, avionic and MMM display update rates, current maneuver number, slave status, G loading, and DA11B-J status.

The aeromodel was rehosted on the PDP 11/55 slave processor. The executive control program for the aeromodel was converted from a program to a subroutine so that direct control could be obtained by the slave executive program. The integration rates of many key routines were modified so that the areomodel would perform at a 50 Hertz update rate. A pitch damper was added to the aeromodel and the roll damper was modified for more realistic flight performance during aerobatic maneuvers. Minor changes to the aircraft's coefficient of lift and center of gravity parameters were made in the interest of improved handling quality.

2.6.5 Pictorial Emergency Procedures/Speech Interaction

The Crew Systems Development Branch of the Air Force Wright Aeronautical Laboratory (AFWAL/FIGR) performed a Pictorial Emergency Procedure Speech/Integration (PEPSI) study which compared different methods of communicating emergency procedures to the pilot. The emergency procedures were communicated using the following three methods.

A) A pictorial display depicting the emergency and the recommended emergency procedure.

B) An alphanumeric display presenting the emergency procedures in a text format.

C) An aural warning and checklist presented by the computer in machine generated speech.

Systems Control Technology provided systems integration support

needed to tie Discovision video players into the DIGISYN facility, programming support needed to generate the alphanumeric display and PDP/NOVA communication driver software and systems integration support needed to tie the newly developed software into the existing DIGISYN software package. An overview of the new software generated for PEPSI is shown in Figure 2.6.5-1. The following specific tasks were performed.

RSX-11M System Generation - A new RSX-11M system generation was performed for the DIGISYN PDP 11/50 computer system. This new operating system was required in order to make use of a DZ11 multiplex line interface purchased for communication with the Discovision vodeodisc players. All other hardware used for the previous simulation effort (SPAM) was included in the new system.

PDP 11/50 - NOVA Communication Software - Three assembly (MACRO) language routines (NOVA) were written to provide a generalized interface to an RS-232 channel through a PDP-11 interface card. Collectively, these routines made up the DL11 MACRO program which handled all communication between the PDP and NOVA computer systems. All three routines were interrupt driven and used the RSX-11M connect service to intercept the interrupts. An I/O page mapping routine was written to provide access to the DL11 registers. In order to provide this specialized control over the DL11 interface card, the operating system was not informed of the presence of the DL11 at the time of the SYSGEN.

NOVA Computer Software - The main purpose of the software generated on the NOVA computer was to provide two-way communication between the pilot and the voice recognition/generation system. During those experimental conditions where the pilot was commanding the cockpit by voice control, the NOVA software was used to control the ASTEC recognition software. In the experimental conditions where machine generated voice responses were required, the NOVA software communicated with the DIGISYN computer to obtain a number corresponding to the

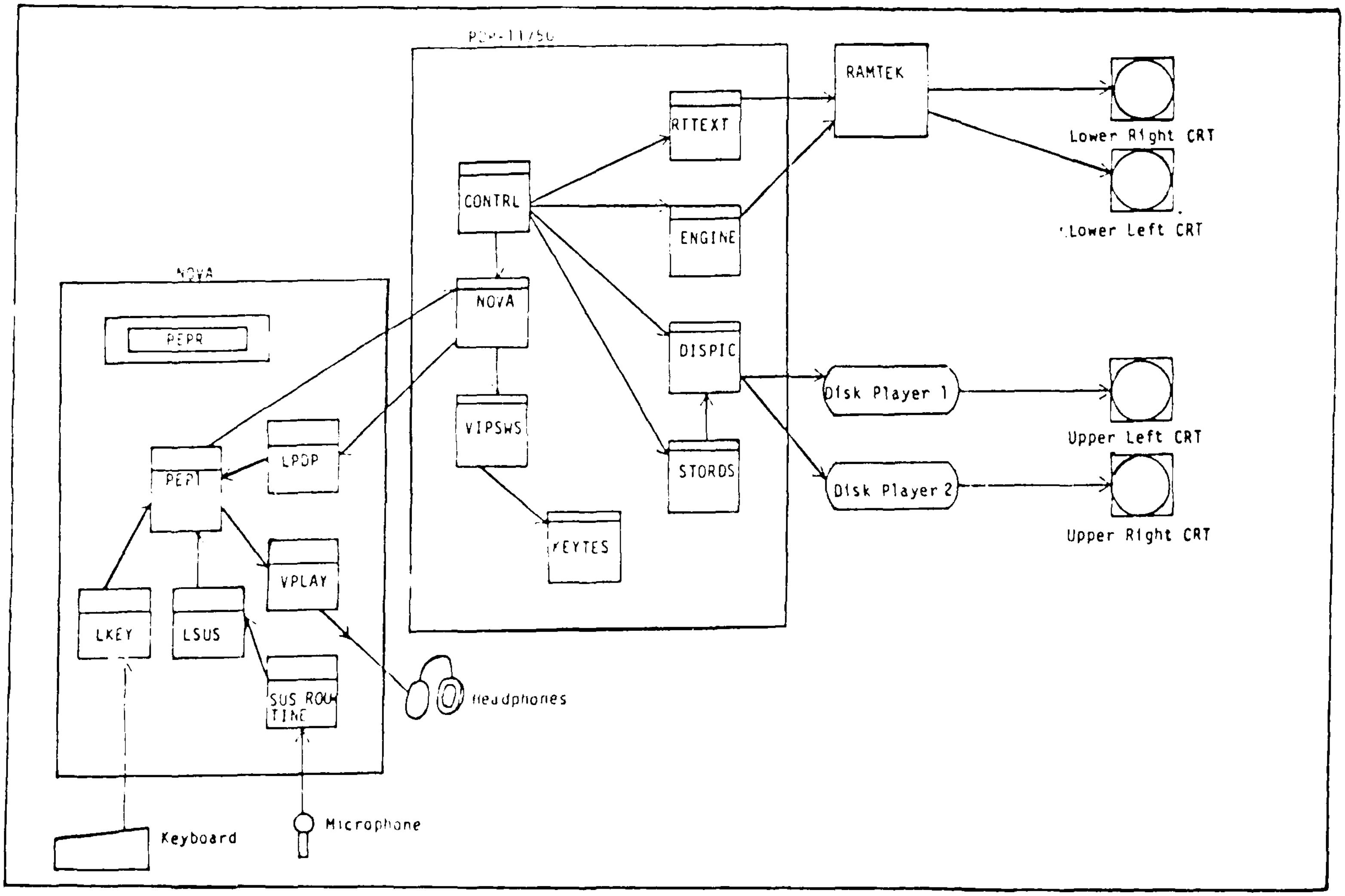


Figure 2.6.6-1 PEPSI New Software Overview

phrase to be generated, and then passed this data along to the voice generation software for output.

Four specific routines were written for the NOVA computer system. They were: PEP1, the executive controller; LPDP, the routine used to communicate with the PDP; LSUS, a routine which "listened" for pilot voice commands; and LKEY, a routine which processed inputs from the NOVA computer terminal.

<u>Alphanumeric Display Software</u> - In one of the experimental conditions, the pilot was provided with an alphanumeric display showing the actions required in response to a pseudo emergency cockpit condition. A general purpose routine (RTTEXT) was written which built a vector of RAMTEK commands needed to display the ASCII text on a cockpit monitor. Functions such as clearing the display and changing text color were built into the software and controlled through the calling sequence.

<u>Discovision Display Software</u> - In one of the experimental conditions, the pilot was provided with a display pictorially showing the actions required in response to a pseudo emergency cockpit condition. The pictures presented to the pilot had previously been recorded on video disc and could be identified by a specific frame number. Software (DISPIC) was written which established communication between the PDP host computer and a microprocessor built into the video disc player unit. Once communication was established, the video disc players were commanded to display the pictures required of the specific emergency task.

Throughout each experimental flight, the pilot also had at his disposal a stores status picture generated by a second video disc unit. Unlike the emergency displays, the stores status picture was always shown and represented the current state of the aircraft's external stores. A routine (STORES) was written to gather stores information from the DIGISYN multifunction control display, determine if a video disc picture existed that represented the current stores status, and if so, command the video disc unit to display that picture.

All of the videodisc, NOVA computer, and RAMTEK communication software was controlled by a set of executive control routines (CONTRL) also written in support of the PEPSI software effort. These executive control routines were needed to schedule all communication with the PDP computer system so that no information would be lost.

Modification of DIGISYN Software - One of the goals of every software development effort on the DIGISYN facility was to create software that could be used not only for the current study, but for future studies as well. The PEPSI software package benefitted from this philosophy by making use of the aeromodel, data recording, data reduction, multifunction keyboard, and flight display software used for the Speech Applications to Multifunction Control (SPAM) study.

Because these routines were used with an operating system with a 100 Hertz clock, all self-scheduled routines were modified for use with the 60 Hertz clock being used in the PEPSI study. The following describes the additional modifications made to the existing DIGISYN software.

- AFLOAD - The aeromodel software was modified to provide a 20% increase in drag to better reflect aircraft performance with the stores load required in the mission. All code pertaining to digital to analog calculations was commented out. Calls to the namelist were also commented out.

- DATA1 - The data recording software was modified to reference the specific performance variables needed for this study. Additional logic was added to this data recording routine for communication to both the executive control software and the multifunction control display software.

- DATA2 - The data reduction software was modified only slightly. The output data file name was changed to PEPSI.DAT, the baseline airspeed reference was changed to 480 knots, and all routines were "cleaned up" by removing references to variables not used.

• ENG - The majority of routines that make up the engine display software had to be modified because they had not been used in recent studies. Access to the system common area of memory and the use of Include statements was changed. To make the software more efficient, all code for generation of a monocrome engine display was removed, as was code for communication with the caution warning panel and code for engine shutdown. New code was added to the engine display software for communication with the executive control task. This new code enabled the display to provide the pilot with alphanumeric feedback during an emergency task. Modifications to the display format included limiting the fuel flow bar to 5300 LB/HR, rescaling the RPM, limiting the RPM to [illegible] [illegible] and including amber regions for display of the hydraulic [illegible] parameters.

• FLTDIR - The flight director software was modified to go to waypoint #6 at track advance and to direct the pilot to the target rather than a release point near the target. Access to the UFCD LED display through the use of a namelist was reactivated.

• HUD - Most of the modifications made to the head up display software involved adding a check for a flight master mode of 4. This allowed the use of the integrated HUD symbology while in the NAV BOMB mode. Four new legends were added to the HUD legend data set to reflect changes made to the multifunction control display. The pull-up queue (the big X) was disabled during weapon delivery.

• KEYTES - The multifunction control display software was modified to determine whether switch inputs were coming from voice or manual control. Some of the legends on the stores display were changed to reflect the current stores load. Switch #1 was activated on the stores display page. All references to master modes other than CCIP or NAV BOMB were commented out to save memory. The task scoring subroutine was modified to reflect the

current experiment task sequences. All task tables were generated.

- MSNSET - The majority of changes made to the mission setup software involved the modification of the waypoint locations and weapon loads. The keyboard scoring task table information was also modified. Various switch flag settings were also changed for proper initializations of the aeromodel and cockpit status displays.

- STATUS - The experimenter's status display software was modified extensively to present task and flight performance data. The software was written so that the status display would be self-scheduled at a one Hz rate.

2.6.6 Microprocessor Application of Graphic and Interface Communication

SCT supported the development of a dynamic mockup which was used for testing possible applications of color flight displays and voice technology for the Advanced Tactical Fighter of the future. The initial configuration of MAGIC consisted of four microprocessors, two graphics systems, hard and floppy disc drives, video disc systems, a Votan voice recognition/generation system, a Colecovision game, color monitors, test operator's console, and required hardware interfaces. SCT was specifically tasked with the development of data recording, data reduction and aeromodel software for the MAGIC system. All software was written in the PASCAL language using an MPM operating system. The following tasks were performed.

DATREC Software Development - The data recording software developed for the MAGIC system was written to take flight performance and voice/keyboard switch hit data supplied by the realtime program and store this information in a file on a pseudo-disc in sequential record format. The specific data collected were switch mode (voice or key-

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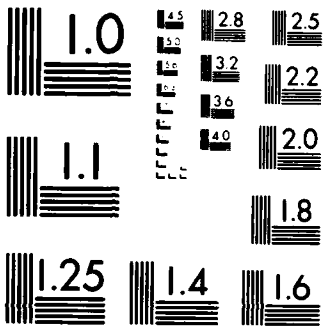

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

board), mission code, pilot number, matrix number, task number, task code, deviation from commanded airspeed, deviation from commanded pitch angle, deviation from commanded bank angle, number of switch inputs, number of switch inputs expected, time to initiate a task and total task time. The design of the software allowed for the collection of the airspeed, bank and pitch deviation measures at a rate of up to 10 samples per second. All other data were collected as needed.

The DATREC routine was written as a PASCAL procedure callable by any executive program, assuming the calling program had access to the data that were being collected. All data were defined as global variables, eliminating the necessity of calling arguments.

DATA2 Software Development - The data reduction software written for the MAGIC system was a logical extension of the data recording software. DATA2 was written to convert the raw flight performance and voice/keyboard switch hit data, placed in a file by DATREC, into summary statistics for output to both a floppy disc and hard copy printer. The summary statistics included average error, absolute average error, rootmean square and standard deviation of horizontal steering, vertical steering, and airspeed errors for both pre-event and event data.

Unlike the data recording software, which was written as one callable PASCAL procedure, the DATA2 software consisted of a main program with four procedures which was either chained to an executive control program or called as a stand-alone program.

AFLOAD Software Development - The aeromodel software hosted on the MAGIC system consisted of 13 PASCAL procedures stored in 11 modules that were used to solve the equations of motion of an A-7D close air support fighter aircraft. The program was designed to run nominally at a 10 Hz or faster rate and had four modes of operation. They were Standby, IC, Trim, and Run.

In the standby mode, no dynamic programs were called or updated. This allowed the aircraft to essentially be "frozen" in any current state or flight condition. The Initial Condition (IC) mode was used

to initialize the simulation integrations and timers to a "time zero" state via a simulation control panel. All of the simulation dynamic programs were called in this IC mode. Each routine was written to perform its own initialization process. The Trim mode was an interim mode where the program trimmed the aeromodel to straight and level flight at the specified conditions. The Run mode allowed the update of each of the routines at a 10 Hz update rate. The "airplane" was flown in this mode. The aeromodel software was actually a FORTRAN to PASCAL conversion of the aeromodel software written for the DIGISYN facility. For the most part, the logic was not changed during the conversion. A decision was made to attempt to retain the actual code wherever possible in order to minimize the risk of corrupting the logic.

In an effort to retain as much flexibility as possible, switch flags were retained to control the various parts of the aeromodel software. The control over these switch flags was attained via a control terminal.

2.6.7 Advanced Control/Display Conclusions and Recommendations

In supporting the Advanced Control and Display effort at WPAFB, we found that our role in the work being performed in the laboratory not only encompassed the realm of software development, but also involved the areas of systems analysis and systems engineering. In many cases, the level of support needed for a simulation development task included much knowledge of the hardware being used in the effort as well as an understanding of the experimental design and statistical techniques being used in the study. SCT felt very comfortable in all areas of the experimental effort because of the diversity and experience of the SCT staff. For example, in developing the data recording and data reduction software for the MAGIC system, a number of disciplines, other than simple software coding, had to be represented. Even though the software routines were developed using the existing DIGISYN software as a model, the task was not one of a straight FORTRAN to PASCAL conversion. This task required knowledge of the hardware being

used for data storage, an idea of the number and types of data to be collected, and an understanding of the phases of data collection and frequency of collection. The ramifications of collecting data too frequently or too infrequently had to be analyzed. In developing the data reduction software, some knowledge of statistics was required to arrive at the best equations for "collapsing" the data. Some human factors input was also needed to produce a final result that was easy to read and easy to interpret, but also compatible with existing data analysis programs.

Not only was a diversity of experience required for this timely completion of any assigned task, we feel that adequate planning was an equally important prerequesite for satisfactory task completion. Before any software was written, we felt that requirements analysis should be done to identify the problem at hand and to devise an approach to the development of any software. In a few instances, a general task was defined, but no exact specification was included. For example, during the MMM simulation software development effort, SCT was required to provide an experimenter's status display. It was known that some type of mission phase data would be displayed as well as feedback showing what the pilot was doing and what the hardware and software were doing at any given time during the experiment, but a specific display format was not identified. Before any software was written, a proposed status display format was developed and, through an interative process, the final format was agreed upon. From this final product, the specific requirements were defined and the coding of the software went quickly and efficiently.

A major component of this iterative process was the ease of communication between all involved participants. Weekly status meetings with all involved participants were found to be extremely helpful in the development of the simulation package. During these meetings, problems were discussed which potentially impacted the work of other simulation team members. By presenting these problems to everyone involved, a solution was generally reached in a rather expedient manner. The biggest lesson learned from these simulation efforts was the need for open communication. The answers to potential stumbling

blocks were many times only a telephone call away.

Recommendations for the Future

During every simulation effort, minor problems arose which at times hampered the development of the simulation software. The problem which most frequently impacted the simulation schedule was the failure of system hardware. In almost every study run using the DIGISYN facility, the display generating hardware malfunctioned. Section 2.6.2 describes the recommendations made in this area.

In the MAGIC system, the needs seem to be in two areas. The first area of focus for the future should be in the upgrading of both the processing and graphics generating hardware. The facility as it stands now does an excellent job of handling the research currently undertaken in the static and slow dynamic display areas. However, future research in the highly dynamic aircraft simulation area will require hardware that can process equations of motion and graphics generation software at speeds much higher than are currently being attained.

Another avenue of future growth recommended for the advanced controls and displays research efforts is the development of a data analysis capability. Currently, the majority of simulation data must be transferred to a large mainframe computer for one phase of the data analysis, and transferred to a second mainframe computer for additional analysis. The transfer of raw data to these machines has not been a trivial matter. The on-line access to these machines has at times been another problem. A fully capable analysis package which resides on the simulation system might be a desirable goal for the future.

2.7 AFTI/F-111 PROGRAM

2.7.1 Program Background and Goals

The mission adaptive wing (MAW) design goal is to maintain aerodynamic efficiency at all speeds and in all flight modes in response to various flight conditions and pilot commands. This is to be achieved by using variable camber wings with smooth, flexible leading and trailing edges (i.e., no spoilers, flaps, or fairings to break the upper and lower surface contours). The flexible leading edge is one continuous segment, and the flexible trailing edge is divided into separate segments for roll control and for shifting the aerodynamic load. Figure 2.7-1 shows a pictorial of the AFTI/F-111 MAW configuration.

The MAW is designed to be a wing for all flight conditions. The cross-section shape of the wing can be changed by an actuation system confined within the airfoil shape. The wing shape can thus be changed to give optimum performance for a given flight condition including take-off/landing, subsonic, transsonic, or supersonic conditions. The variable camber control offers (1) cruise camber control to minimize drag, (2) roll control without spoilers, (3) maneuver load alleviation, (4) gust alleviation, and (5) direct lift. The principal benefits from these features are better maneuverability, longer range, greater fuel efficiency, and improved handling qualities. For the combat pilot, the MAW means faster evasive action, increased survivability, a more stable platform for weapon delivery, and a more comfortable ride to reduce crew fatigue and allow better performance.

Aerodynamic control of the AFTI-F-111 will be accomplished by movement of the wing leading and tailing edge variable camber control surfaces, the stabilons and rudder. Control of the wing surfaces will be achieved via the MAW FCS. Stabilon and rudder control will be achieved via the existing TACT-F-111 FCS modified for the MAW application. Three configurations of the MAW FCS will be provided; an all manual control configuration, followed by a manual plus a maneuver camber control and cruise camber control system and finally a manual

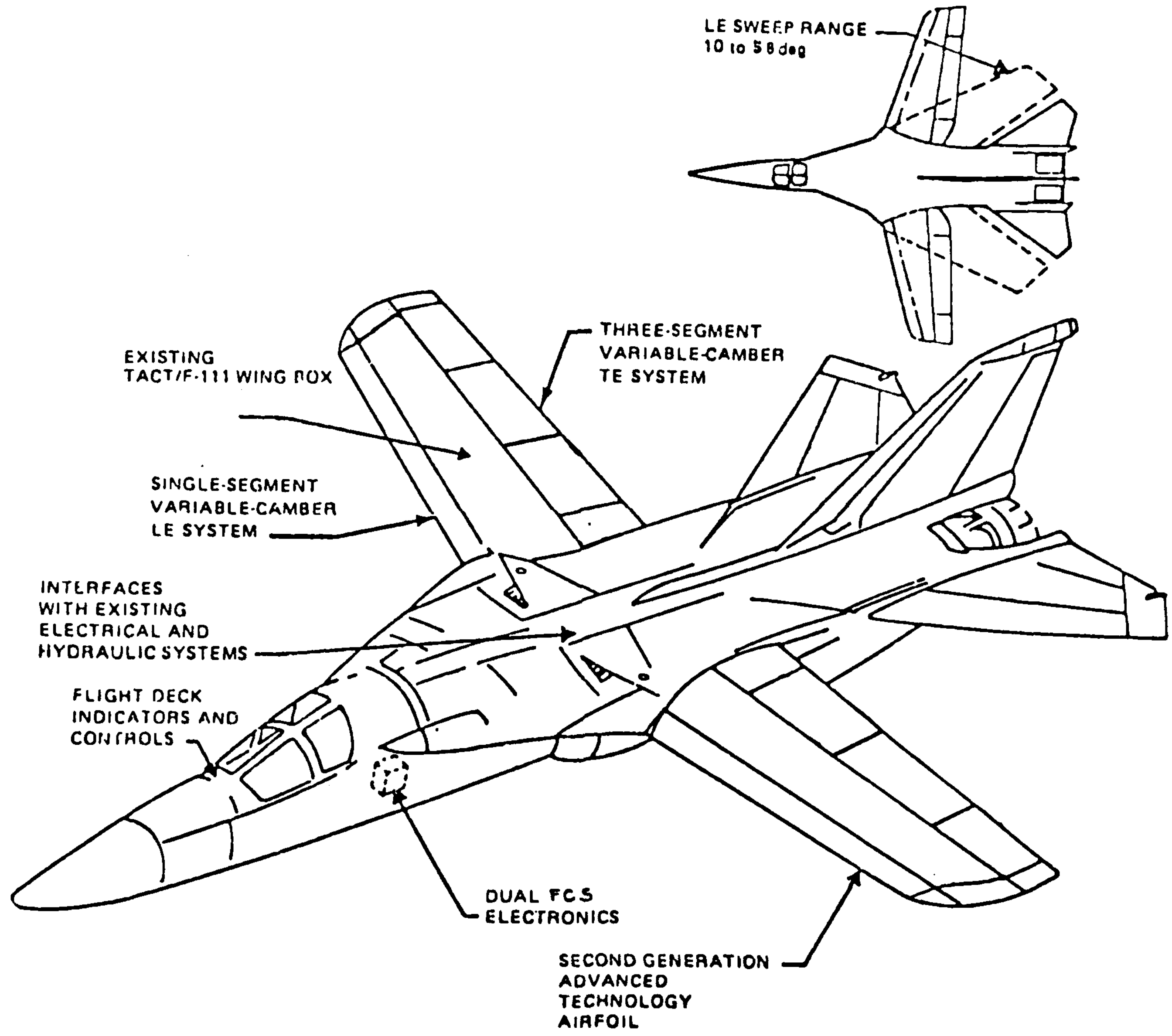

Figure 2.7-1 AFTI/F-111 MAW Configuration

plus full automatic configuration.

The MAW FCS will use a redundant electronic system consisting of analog and digital circuit technology. The system will provide fail safe leading edge control and fail operational control after one failure for the trailing edge roll control surfaces. Functions performed will include control, display, fault detection, isolation and built-in test. The MAW FCS will provide the interface between the pilot and the control surfaces in both the manual and automatic operating modes. Figure 2.7-2 presents a sketch of the wing assembly while Figure 2.7-3 is a schematic diagram of the flight control system showing each major function of the system which controls the wing assembly.

2.7.2 Program Description

The Advanced Fighter Technology Integration (AFTI) F-111 Program consists of two phases. The first phase addresses the design and development of a variable camber (VC) mission adaptive wing (MAW) and includes a flight test program. Testing of the MAW will be performed using a manual pilot-controlled fly-by-wire system for setting MAW leading and trailing edge deflections. This manual system provides for evaluation of general quasi-static aerodynamic performance and for developing flight control parameters.

Phase two of the AFTI-F-111 Program addresses the design and development of a modification to incorporate an automatic flight control system (AFCS) capability for the MAW that is compatible with the manual control system. A second flight test program is planned to evaluate the MAW with automatic controls and demonstrate the performance benefits provided by the AFCS functions.

2.7.2.1 MAW Manual Flight Control System

The manual flight control system (MFCS) phase of the MAW program includes the design and development of a variable camber wing and flight test. Modifications have been made to the pitch, roll, and yaw

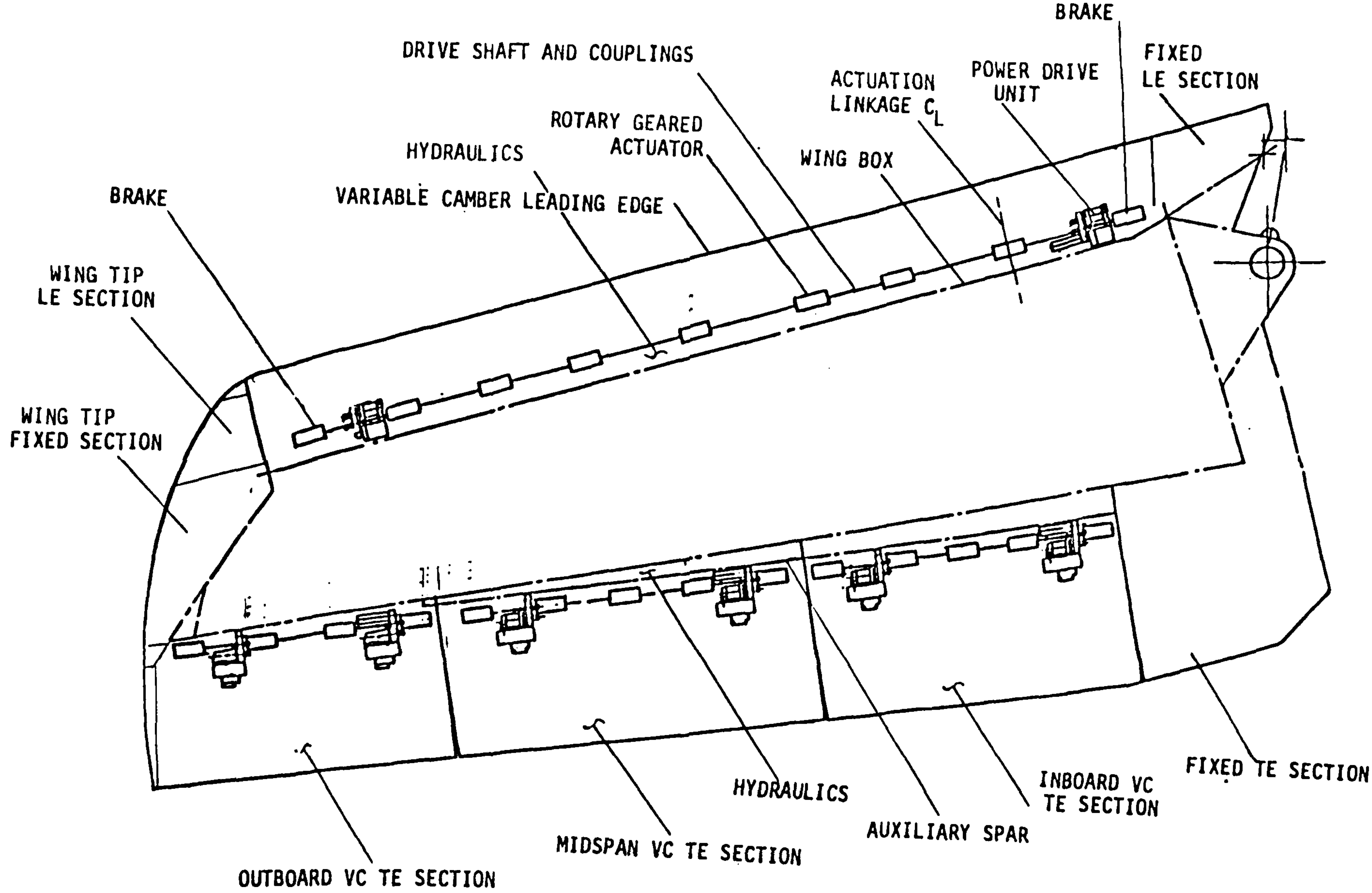

Figure 2.7-2 MAW Wing Assembly

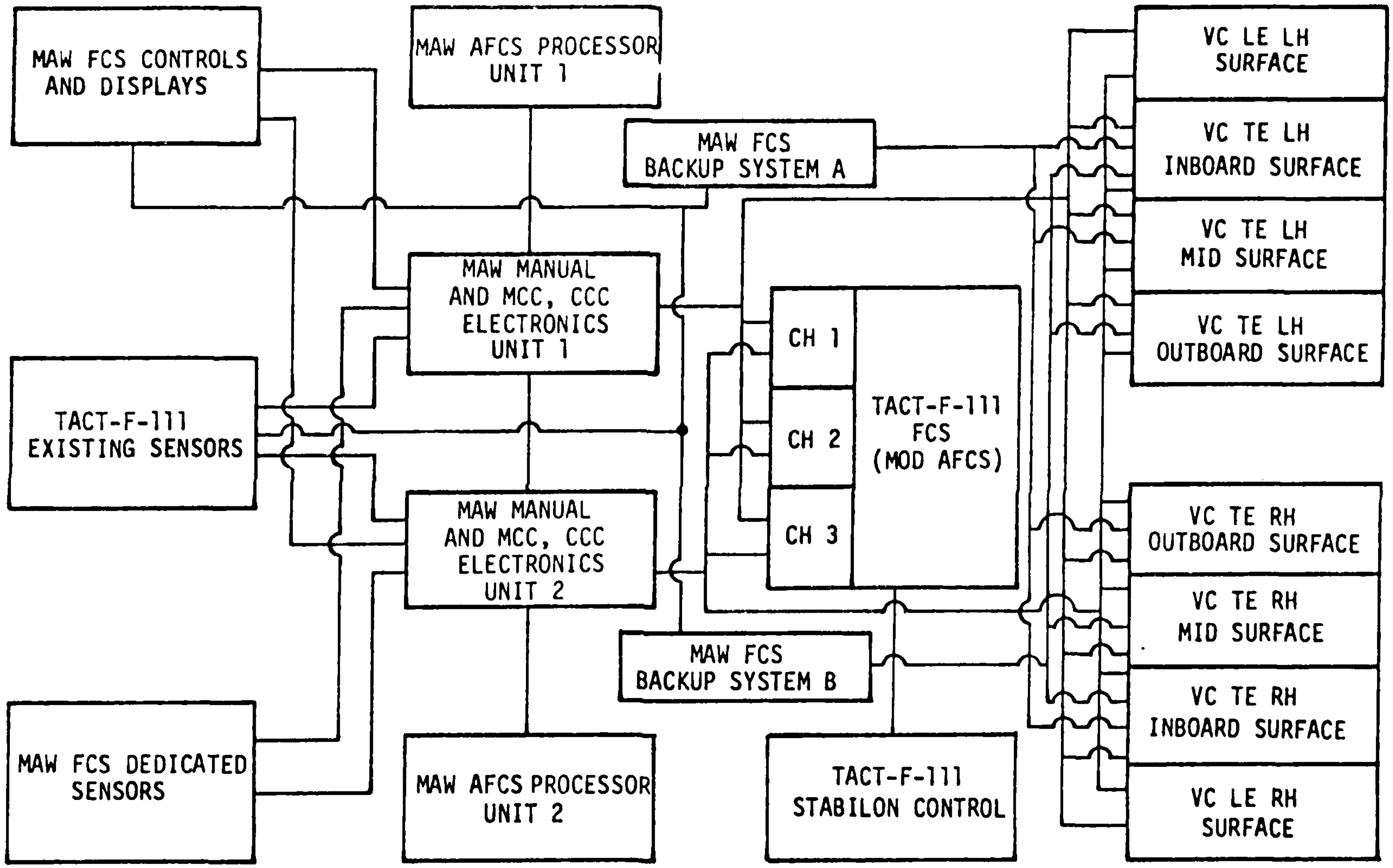

Figure 2.7-3 MAW Flight Control System Schematic Diagram

channels of the TACT/F-111 flight control in order to incorporate the control characteristics of the MAW. Additionally, a MFCS has been developed to drive and control the leading and trailing edge surfaces. The initial system configuration provides manual control of the leading and trailing edge control surfaces in symmetrical pairs, provides roll control via outboard and mid span trailing edge surfaces and provides means to establish the takeoff and landing configuration. The MAW FCS has a dual digital architecture that provides primary control of the MAW control surfaces. A segregated analog system provides for backup roll and limited trailing edge symmetric control for landing in the event of primary system failure.

2.7.2.2 MAW Automatic Flight Control System

The AFCS modes are added to the existing manual flight control system to augment the performance of the aircraft. The four AFCS modes added are:

1. Maneuver Camber Control (MCC)
2. Cruise Camber Control (CCC)
3. Maneuver Load Control (MLC)
4. Maneuver Enhancement/Gust Alleviation (ME/GA)

These modes control the airplane through wing leading and trailing edge surface commands and stabilon commands.

When engaged, the AFCS modes operate parallel to and through the MFCS to control the airplane. This configuration allows the AFCS system to be disengaged at anytime without compromising the safety of the aircraft.

MANEUVER CAMBER CONTROL

The MCC mode continuously positions the MAW wing surfaces to their maximum lift/drag positions during both maneuvering and steady state flight for a given Mach No. and lift coefficient. The wing surface positions are computed based on entering stored tables of wing leading and trailing edge flap positions that are functions of lift coefficient, wing sweep and Mach number. These stored tables are

based upon picking points of maximum L/O from the wind tunnel generated drag polars. These data have a single adjustment for dynamic pressure effects. The flaps on the right and left wings are commanded symmetrically for this mode. The MCC leading and trailing edge flap commands are extracted from tables where independent variables are airplane lift coefficients, Mach No. and wing sweep. Lift coefficient is calculated from measured normal acceleration g, computed weight based on initial empty weight and remaining fuel, measured dynamic pressure and reference area. The calculated MCC flap commands are filtered by 2.0 rad/sec first order lags. The acceleration input to the lift coefficient calculation is prefiltered by a 20 rad/sec lag.

CRUISE CAMBER CONTROL

The CCC mode is an on line optimization process that varies the trailing edge flap position to maximize horizontal velocity. This mode will engage when the altitude hold mode is engaged at constant power level angle. The mode operates by incrementally moving the trailing edge flaps either up or down in such a fashion as to maximize forward speed. The operation of the mode is based on comparing actual and predicted forward velocity changes as related to flap movement. The mode uses the integral of longitudinal acceleration to compute forward speed changes. The velocity changes are sampled at 5 sec intervals to form a data set used in estimating the two parameters for a first order longitudinal velocity predictor based on least square techniques. With this predictor, the future forward speed of the aircraft can be estimated. The algorithm will next make a flap change and, after allowing enough time for short period dynamic effects to decay, will make a velocity change measurement. This measurement is compared to the estimated velocity change if the flap was not deflected. If the actual speed change is greater than the estimated speed change, then the most recent flap change was beneficial and the process continued. If not, the optimum flap setting has already been reached.

MANEUVER LOAD CONTROL (MLC)

The MLC system prevents the wing root bending load from exceeding the limit load level. The MLC mode has no effect on control surfaces or the operation of the other AFCS modes when the wing root bending moment is below the threshold of 95 percent of the limit load. Above the 95 percent threshold, the MLC system commands the outboard trailing edge surfaces to limit the root bending moment to the threshold value. At all times, both midspan and inboard surfaces are free to respond to other MFCS and AFCS commands. The MLC mode has independent right and left wing systems for asymmetric flight conditions. For certain operating configurations, the MLC system also commands the stabilon through pitch damper inputs to control undesirable airplane transients. To achieve the aim of limiting the wing root being moment to an acceptable level, the MLC system automatically shifts the wing center of pressure inboard by moving the outboard flap upward to reduce the lift on the outboard section of th wing. By moving the center of pressure inboard, increased lift is allowable and can be demanded by other system inputs (although slightly higher angle of attack is required). By acting automatically to limit bending moment a more severe maneuver can be commanded. The approach used for the MLC mode is to compute an estimate of the bending moment at the wing root using accelerations, weight, dynamic pressure, mach number, leading and trailing edge surfaces positions and stabilon deflection rate (filtered) and if this estimate is greater than 95% of the threshold, command the outboard flags until the 95% threshold is not exceeded.

MANEUVER ENHANCEMENT GUST ALLEVIATION (ME/GA)

The purpose of this mode is to significantly improve the airplane normal acceleration response to a pilot command while simultaneously reducing cockpit normal acceleration response to turbulence. The ME/GA mode is designed to integrate these two functions such that the performance of each function is in no way degraded by the presence of the other function in the mode. The ME/GA mode was designed using linear quadratic Gaussian regulator theory to generate a full state optimal gain matrix and Kalman filter. A modal residualization process was used to reduce the full state system to a lower order system

suitable for implementation on a flight computer. The requirement of improved command response has been realized by using an explicit model follower feedforward controller in the control system. The feedfoward controller gains are synthesized as part of the optimal regulator solution. The ideal model is a first order lag with a break frequency tuned to provide a good response without excessive overshoot. The ME/GA mode uses three sensors: normal acceleration at the cockpit nz pitch rate, and pitch stick position. In addition, leading edge position and trailing edge position commands are input from either the manual mode or MCC AFCS mode. The ME/GA system is designed to command the flaps to these latter inputs in the absence of any other commands. The sensor measurements are used as inputs to the Kalman state estimator. In order to provide the same overall stick sensitivity, the sensed and commanded accelerations are compared with the difference used to generate a stabilon command. This causes the airplane to respond to the commanded acceleration level.

2.7.2.3 MFCS and AFCS Implementation

The MFCS will be implemented and flight tested in the first phase of the program. Upon completion of the manual flight test, the manual system command processors will be reprogrammed to add the MCC and CCC automatic control system modes. Following evaluation of MCC and CCC modes, two additional command processors will be added to handle the MLC and ME/GA modes. The two additional command processors (AFCS processors) will communicate directly to the manual command processors. The two manual command processors will communicate with each other on a cross-channel data bus and individually to the AFTI/F-111 flight control system. The cross - channel data bus provides a means for failure checking between command processors. The cross - channel data bus is also interfaced to a digital data interface unit for flight data recording and telemetry. A top-level system diagram is shown in Figure 2.7-4.

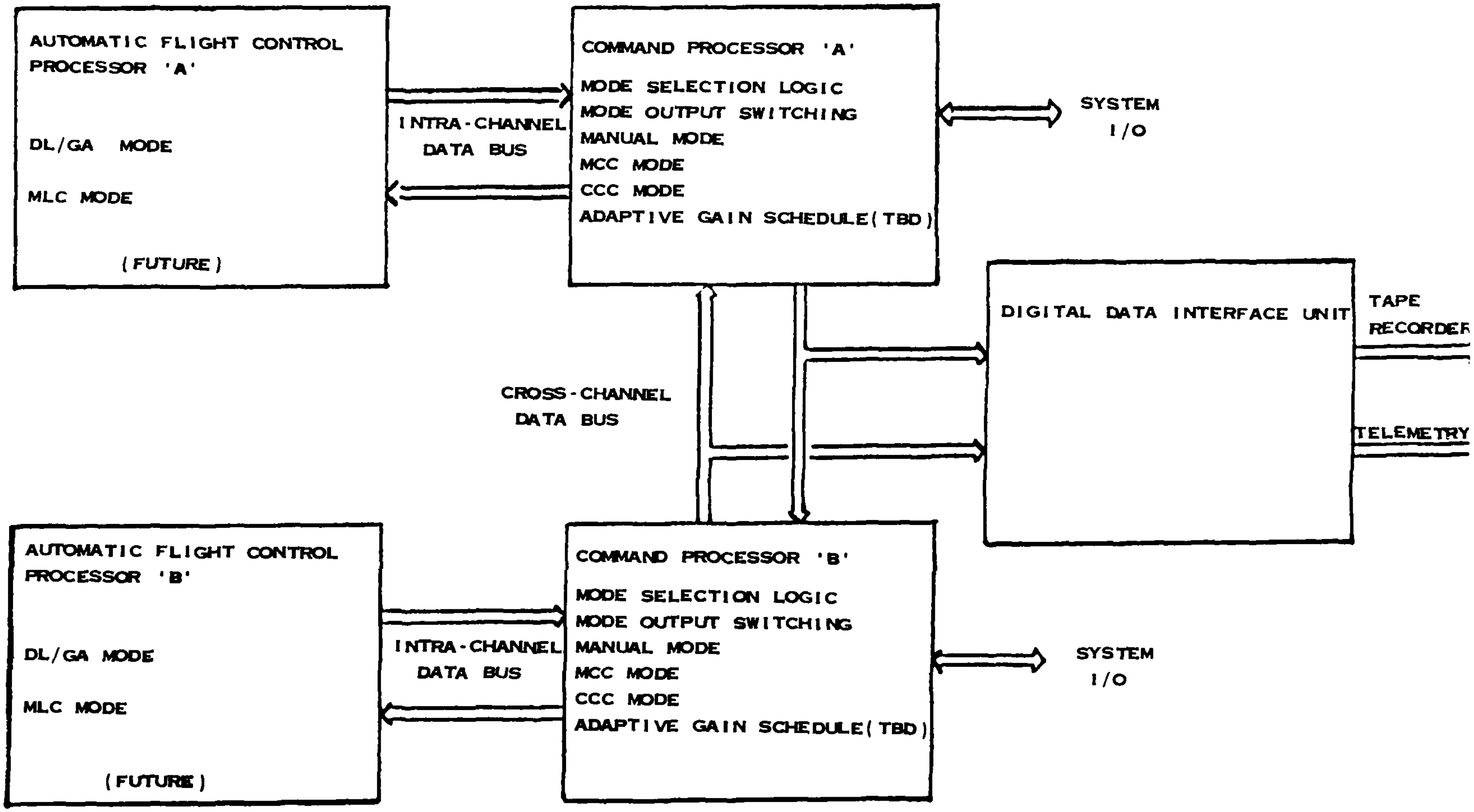

Figure 2.7-4 Top-Level System Diagram

2.7.3 Program Status and Plans

The wings have been delivered and installed on the TACT F-111 aircraft at NASA/Dryden. The command processor software has completed software verification testing in a software test laboratory which utilized the command processors and hardware test panels which emulated many of the aircraft functions. Preliminary functional testing has been performed on the aircraft which has verified the MFCS functional requirements. This functional testing was performed on the aircraft using two command processors which had passed hardware functional testing, but were not yet soldered, sealed or had undergone environmental tests.

The purpose of this preliminary aircraft functional test was to identify any hardware interface discrepancies and any other discrepancies which might exist while changes could be made more easily before the units were sealed. As a result of this preliminary functional testing, minor problems were identified in interfaces, design, and test procedures. These problems have been resolved and the aircraft MFCS functional tests are scheculed for the March/April time frame. Upon completion of the aircraft functional tests, ground vibration tests will be performed followed by final preflight tests. Flight test is expected to be initiated in the August/September time frame.

2.7.4 Work Accomplished

SCT has been providing systems and software support to AFWAL/FIMS for the AFTI/F-111 MAW program. This support has occured in three areas; software management, simulation support, and control system design.

2.7.4.1 Software Management Support

SCT has provided software support to address the management aspects of the AFTI-F-111 MAW Manual Flight Control System (MFCS) and Automatic Flight Control System (AFCS) software development. This support consisted of developing and maintaining a system level understanding for the MFCS and AFCS and actively participating in the

software development management milestones. Support which was provided consisted of:

- Review of contractor software development plans to assess whether planned management and technical activites will provide adequate Air Force and Boeing visibility and control into the software development of the MFCS and AFCS.
- Review of contractor monthly progress reports to maintain currency on system and software development status.
- Active participation in the software requirements reviews, PDRs, and CDRs to include review of software documentation and assessment of the adequacy of requirements, plans, and specifications presented.
- On a continuing basis, review of system level documents and technical reports to stay current with design and development activities and maintain a system level understanding.

Because the MAW software development is a multi-phased development effort, a number of planned software versions will evolve during the course of the program. SCT has worked closely with the Air Force and NASA in performing a critical review of the contractor software development plan, and in turn provided guidance in the areas of software documentation, software configuration control, and software development milestone reviews. SCT has reviewed all developing contractor software documents and many system documents, providing document review comments to the Air Force. Also, SCT has actively participated in all system and software design reviews of the MAW program, providing comments, trip reports, and generating RIDs (review item disposition), as required.

2.7.4.2 Simulation Development Support

SCT has also provided simulation development support at NASA/Dryden. This support consisted of detailed review of system and software requirements for the MAW MFCS and AFCS, and assistance in

implementation of these requirements into a functional simulation of the MAW system. An example of specific activities includes:

- -Integration of aeromodel data with AFTI/F-111 real-time simulation.
- -Update of various simulation models such as landing gear and ground effects.
- -Optimize models for real-time execution.
- -Generation of aeromodel check cases.
- -Verification of aeromodel data packages.
- -Rehost of simulation onto MODCOMP computers.
- -Development and integration of software to add MAW control panel to simulation.

SCT provided daily support in the development modification and update of the AFTI/F-111 MAW simulation. Support was also provided during real-time data gather and demonstration runs.

2.7.4.3 Control System Design Support

SCT was requested to look at an alternative approach to controlling wingshape design (see Section 2.5.2). SCT performed a study whose objectives were to define potential multivariable control law structures which are suitable for active wingshape control, recommend design and algorithm implementation techniques, and assess the design impact of a multivariable active wingshape control system.

The scope of this study was limited to a preliminary assessment of multivariable control applied to the AFTI/F-111. The study investigated the integrated design of a multivariable-multifunctional control system based on the application of modern control design techniques. The AFTI/F-111 MAW is an example of the need for such integrated design methods as an aircaraft that combines wing shape control (which is mechanized to continuously control the leading and trailing edge deflections) with conventional aircraft controls (i.e., stabilon, throttle, rudder) for enhanced aircraft performance and handling qualities. This type of control system requires integration of

aircraft stabilization, configuration management and structural load control functions that can benefit the operational performance of the aircraft for takeoff, climb, cruise, combat, and landings modes of flight. The actual mix between control functional requirements and modes of flight varies with aircraft type (i.e., penetration bomber, large transport, cruise missile carrier or fighter).

Modern control design techniques are well suited for the development of complex control systems such as the MAW, for two reasons. First, multivariable synthesis techniques offer a systematic method for optimizing control law structures for multiple control requirements (e.g., drag minimization, lateral control, and maneuver load alleviation for maneuvering flight) where a number of sensor signals and control surfaces are available for the control law. Second, parameter identification techniques would be used to generate flight condition and camber corrections for optimizing the aircraft performance and the required signals for the multivariable control law. The use of parameter identification for on-line flight performance optimization could also be extended to include the aircraft's propulsion system (i.e., inlet, internal, and nozzle geometry).

Specific design features of the designed MAW multivariable multimode flight control system are in SCT Report No. 5339-522-1, Active Wingshape Control System Feasibility Design Study, August 1982.

2.7.5 Conclusion and Recommendations

SCT provided assistance to the Air Force in the areas of software management simulation development and control system design support.

The area of software management addressed those aspects of the developing contractor's approach to planning and managing the development of flight software. That is, SCT reviewed the contractor's approach to software development and monitored the contractor activities during the development process.

With the current trends in computer hardware, software development costs are becoming the major portion in the acquisition cost of systems involving hardware and software. In order to reduce

these costs software management must work toward the following objectives:

-Reduce resource expenditures in software development.

-Improve software development resource estimating.

-Avoid duplicate development efforts.

-Improve quality of software.

-Reduce software maintenance efforts.

The Boeing Company has established company software standards which they profess to use for software development efforts. SCT reviewed these standards and found them to be an excellent approach to software development. The first major impact of these standards was that software documentation would not be prepared according to MIL-STD-483/490, but would use phased software development documents which more closely follow the actual development process. SCT approves of this approach and recommends that this approach be used in future Air Force software development efforts. For the MAW program, because of the reduced magnitude of software development effort, a short form of these documents consisting of 5 documents rather than 10 documents was used. These documents included (1) Requirements, (2) Design, (3) Test, (4) Operating Instructions, and (5) Version Description, which collectively cover the gambit of software development activities from requirements definition to software update and maintenance.

Boeing also has excellent software standards covering configuration management, software quality assurance, software development, and software review. However, the application of these standards to a specific project sometimes requires an interpretation/learning process by individuals unfamiliar with this approach and hesitant to use it. SCT performed in a software management review role of Boeing's software management approach. The scheduled formal reviews (i.e., Requirements Review, PDR, CDR, etc.) provided milestones within the software development process which allowed assessment of the progress of the development. Also, occasional on-site engineering reviews of design and development efforts provided insight to actual software development practices being used.

In general, for the MAW program these reviews (both formal and engineering) were valuable in keeping the Air Force/NASA informed of the development progress and also in making the Boeing personnel adhere to their software standards.

In future development efforts, the Air Force should initially make certain that the development contractor have a well defined, phased software management approach with scheduled review milestones. As the software development progresses, the Air Force should actively participate in the software review process to assure that initial development plans are being met and that these plans are still aligned with final design goals.

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